The Easy Way

HF Antenna Systems

$12.00

J. M. Haerle

THE EASY WAY

AN HF ANTENNA COMPENDIUM

JOHN M. HAERLE, WB5IIR

THE EASY WAY
An HF Antenna Compendium

John M. Haerle, WB5IIR

First Edition 1984
Second Edition April 2004

WORLDRADIO BOOKS
2120 28th St. · Sacramento, CA 95818
916/457-3655 *www.wr6wr.com*
Copyright 2004

ISBN 0-9705206-4-6

ABOUT THE AUTHOR

Born John Marshall Haerle on April 21, 1914, he studied music at Old Miss and LSU and played in a number of swing bands in the 30s and 40s. During World War II, John served in the Navy, first studying and later teaching radio. After the war, he was a mail carrier, radio repairman and, later, chief engineer of a radio station in his hometown, Quincy, Illinois.

Then John joined Gates Radio Company, serving first as salesman and later as manager of the New York office. While in New York, he went with Collins Radio where he became head of the broadcast division and eventually Vice President of Public Relations and Advertising.

In 1978, John retired and devoted much of his time to Amateur Radio, conducting lectures and seminars on antennas and giving a license class nightly for the Amateur Radio community. There are many hams who claim to be a graduate of the University of WB5IIR! He received many awards from MARCO and DARC and it was after a presentation at the August 1st (1984) meeting of the Dallas Amateur Radio Club that John was killed in a car accident on his way home. He was struck by a drunk driver who had had seven moving violations in the previous three years. The driver paid a fine and court costs and was given five years' probation.

John realized an enormous amount of his human potential. At 69 years of age, he bought a computer on which to write this book. He developed his own radio and electronic skills to a high degree, becoming a respected expert in the field. Most importantly, he found the meaning of the phrase "To find your treasure in Heaven, you must give everything away."

DEDICATION

This book is dedicated to M. Walter Maxwell, W2DU, without whom it would never have been possible.

Please credit Mr. Maxwell with everything good about it and blame me for the rest.

—WB5IIR

FOREWORD

Since this book is a by-product of my participation in the MARCO net, let me tell you, first, something about MARCO:

In the fall of 1965, at the Astor Hotel in New York City, Doctor William L. Sprague (WA6CRN), held a meeting of physicians and dentists who were interested in forming a medically-oriented Amateur Radio organization. Using a list of medical and para-medical hams which he had collected over the years, Doctor Sprague came up with an original founding group of 95 members. The MARCO group was then formalized at a meeting in New York in April, 1966.

MARCO has grown steadily since that time to its present number, 648 physicians, dentists, veterinarians and related medical personnel, plus associated non-medical members such as myself. The organization is represented in all U.S. and Canadian call areas plus 96 DX members in 35 foreign countries.

The purpose of MARCO is to exchange medical and technical information and, wherever possible, to be of public service by assisting in medical emergencies (such as created by natural disasters) and handling priority traffic.

Schedules include a nightly net on 40 Meters, and other special groups meeting less frequently on both 40 and 20 Meters (including a CW group).

Early in 1981, MARCO decided to dedicate the Sunday evening meeting of the regular 40-meter net to a MARCO ANTENNA WORKSHOP, created to assist members with their antenna systems, and intending to help improve the effectiveness of the net operation. I was invited to conduct this activity and have continued to do so (at this writing) for three years.

During this period, I have researched and produced many talks on a wide variety of antenna subjects,and have kept the mails busy answering questions and sending copies of the talks. As a result, I have been getting requests for a collection of the talks, in the form of a book. This is the result.

The book will maintain the tone and format of the "on-air" talks. As a result, there will be no illustrations, since it was necessary to create mental images for the listeners. I think you will find, though, that this technique has produced a book which is very easy to read and understand.

— WB5IIR

INTRODUCTION

Kurt N. Sterba, K5KNS

As longtime readers of my column (and I thank you muchly) know, I have savaged a great many antenna books.

It was not done with any great joy. I was saddened and angered that Amateur Radio operators were the unwitting victims of so much awful non-information.

I considered it a disgrace that a great many publishers would foist on an unsuspecting public so much horrendously erroneous drivel.

I'm greatly pleased that ***WorldRadio*** is publishing "The Easy Way" by the late John Haerle, WB5IIR. Prior to his untimely passing John would write wonderful letters to me regarding my attempts to separate fact from fiction (garbage).

I had read his book (several times) and had praised it in my column. This book is a true RARITY! There are no mistakes nor is there any false information in it.

I can recommend it wholeheartedly, 100% plus. It is a true learning experience and the Amateur Radio community should be grateful that such a book exists.

TABLE OF CONTENTS

The Fundamentals

The Easy Way....10
Antenna Terminology Revisited....18
Feedline Terminology Revisited....21
Baluns....24
Ground Systems For Vertical Antennas....30
Lightning Protection....31
From BC To Coax....33
Towers....36
Keeping Your Tower Vertical....39

The Basic Antennas

The Dipole....44
The Zepp....47
The G5RV....50
The Windom....52
The Coaxial Dipole....54

Some Special Antennas

The Sloper....58
The DDRR....61
The Beverage....63
The Folded Unipole....66
Vacation Antennas....69
Mobile Antennas....72

Beam Antennas

The W8JK....76
The Yagi....79
The Two-Element Quad....82

The 160 Meter Story

The 160 Meter Band I....86
The 160 Meter Band II....89
Receiving Loops And Preamps....91

THE FUNDAMENTALS

THE EASY WAY

It is a basic truism that you can't get something for nothing, but I am not using "easy way" in this context. Rather, I am using "easy way" as the opposite of "hard way"... and as I talk to hams, on the air or in person, I get the feeling that many of us are, indeed, doing it the hard way. A real challenge, though, is getting hams to believe what I am going to say ... and I am going to set forth some principles that you must accept without reservation before we can develop what follows. Of course, I cannot expect you to accept this "gospel" from just one source, so I begin with qualifying words from several authorities who carry blue-ribbon credentials.

First, to set the tone of this talk, and to pay tribute to one of the great hams (who left us too soon in April, 1980), here is the essential part of an editorial by Jim Fisk, Editor (until his passing) of *Ham Radio Magazine*:

"In the evening when I'm working down in the shop, I flick on the receiver and tune around the 75-meter phone band. I can invariably find an interesting conversation about the sorry state of the economy, the high cost of fuel, the fine golfing in Florida, or a technical discussion on quads versus yagis. There's always something that starts the old adrenalin flowing. The other night, two characters with two-letter calls were holding forth on the low end of the phone band. The technical topic of the evening was transmission lines and, to hear these guys talk, they were the original experts ... when all they really had to offer was a barge full of baloney.

"I don't know where all the feedline myths started, but I suspect it had something to do with the do-it-yourself SWR bridges which first became popular back in the early 1950s. Until then, most amateurs didn't even know about standing waves and, if they did, they didn't seem to care. However, SWR bridges soon caught on, and it wasn't too long before getting caught with your SWR up was synonymous with getting caught with your pants down! Some hams dug into the books, but when they discovered that SWR is caused by a mismatched antenna, it only served to reinforce the myth. If a mismatched antenna causes power to be reflected back down the line, they reasoned, this power obviously wasn't radiated by the antenna. Some even suggested that the reflected power got back into the transmitter tank and was dissipated in heat. Others apparently thought that reflected power was lost forever to some great SWR heaven in the sky. A few well-informed amateurs tried to nip these absurdities in the bud, but it was hopeless ... the disease spread faster than the cure. Transmission lines are too complex to be covered here, but let's bury the myths: First, reflected power is not lost nor does it heat up the tank circuit of your transmitter. Second, if the feedline has low loss, as is the case on the HF bands, increased loss due to SWR is so small that you can forget about it. Since a 10:1 SWR on 100 feet of RG8U at 4 MHz increases loss by less than 1 dB, don't worry about the fact that the SWR rises above 2:1 at the band edges ... the station at the other end won't be able to tell the difference. If your transmitter doesn't like to load into a mismatch greater than 2:1, buy or build yourself an antenna tuner and save yourself a lot of grief by forgetting the SWR on the line to the antenna if it's within reasonable limits, say 10:1."

Jim was a great admirer of our next authority, M. Walter Maxwell, W2DU, a ham since 1933, with impeccable credentials in the fields of antenna and feedline design. His background includes, for example, building antenna fields for the FCC, on this continent and in Hawaii. Then, in 1949, he joined RCA and, in 1958, became a charter member of RCA's Astro-Electronics Division. From 1960 until his retirement, he was in charge of the antenna laboratory and test range at the RCA space center in Princeton, New Jersey. More than 50 orbiting spacecraft antenna systems were designed solely by Maxwell, including Echo I and all Tiros-Essa satellites. Walter is also a very "down-to-earth" ham. He is best known to amateurs for a series of articles entitled "Another Look At Reflections," which ran in *QST* from 1973 through 1976. The first of these was subtitled, "Too Low A SWR Can Kill You." In this one, he said: "Judging by what we hear on the air, nearly everyone is looking for a VSWR of 1:1. Question why and the answer may be, 'I'm not getting out on this

frequency because my SWR is 2.5:1 ... there's too much power coming back and not enough getting into the antenna' ... or, 'If I feed a line having that much SWR, the reflected power flowing back into the amplifier will burn it up ... or still, 'I don't want my feedline to radiate.' Any of these answers shows misunderstanding of reflection mechanics, symptomatic of the current state of education on this subject. Rational and creative thinking toward antenna and feedline design practice has been absent for a long time, having been replaced with an unscientific and thought-provoking attitude, as in the days before Copernicus persuaded the multitudes that the universe did not revolve around the earth. This situation originated with the introduction of coaxial transmission lines for amateur use, about the time we got back on the air after World War II, and has gained momentum since SWR indicators appeared on the scene, and since the loading capacitor of the Pi-net tank replaced the swinging link as an output coupling control. We are in this state because so much misleading information has been and is still being published concerning behavior of antennas which are not self-resonant, feedline performance in the presence of reflections when mismatched to the antenna and, especially, the meaning and interpretation of SWR data. Articles containing explicitly erroneous information and distorted concepts find their way into print, become gospel and continue to be perpetuated with chainletter effectiveness. These gems of intuitive logic include:

"1. Always requiring a perfect antenna/feedline match.

"2. Evaluating antenna performance or radiation efficiency only on the basis of feedline SWR ... the lower the better.

"3. Pruning a dipole to exact resonance at the single operating frequency and feeding it with an exact multiple of a half-wave coax ... no other length will do.

"4. Adjusting the height — perhaps just lowering the ends into an inverted vee to make the resistive component equal to the line impedance, or ...

"5. Subtracting percent reflected power from 100 to determine usable percentage of transmitter output power (nomographs have even been published for this erroneous method).

"As a result of these misdirected concepts, we have been conditioned to avoid any mismatch and reflection like the plague ... one-to-one all the way! ... Sound exaggerated? Not if the readers' receivers are tuning the same amateur bands as the author's!

"In the current vernacular, one could say that we have a severe SWR hangup! In many instances, from the viewpoint of good engineering, this hangup is inducing us to concentrate our impedance matching efforts at the wrong end of the transmission line. It is ironic that we should be in this situation, because the amateur is generally quite practical when it comes to following theoretical considerations. In this case, though, we have been following the perfect-match theory down the narrow path because many of the aforementioned articles have misled us to believe that all reflected power is lost, with never an inkling that, properly controlled, reflections can be turned to our advantage in obtaining increased bandwidth, which we are presently throwing away."... so says Walter Maxwell.

Another accepted ham antenna expert, Walter H. Anderson, VE3AAZ, writing in *Ham Radio Magazine*, says, in part: "A UA9 I worked recently said he was using a Zepp antenna. It occured to me that at least one generation has passed since the Zepp was, by far, the most popular antenna. We didn't realize it then, but the Zepp's standing wave ratio probably ran as high as 30:1. However, history shows that the Zepp put out a good signal. Thus, it would seem that the Zepp didn't really have the side effects we hear attributed to high SWR nowadays — high plate dissipation, radiation loss and all the rest. I don't suggest we dismantle our beams and go back to Zepps. Rather, I propose to show that transmission line theory, properly understood, is free of the contradictions that arise when discussing SWR, reflected power, line losses and other phenomena associated with antennas and feed systems."

Further along, Walter mentioned the transmatch: "It's easy to dispense advice on obtaining low SWR, but it's much more difficult to specify cures for same. If you must live with kinky antenna impedances, then you might consider using an antenna tuner. If air-dielectric capacitors and silver-plated inductors are used, power loss from the tuner will be negligible. An antenna tuner will allow the impedance presented to the transmitter to be close to

50 ohms, and the transmitter will be be satisfied. Such a tuner also pays dividends on receiving."

Jim Fisk, Walter Maxwell, Walter Anderson ... note how the experts agree ... and I hope the foregoing will encourage you to have faith in what follows. Here is what I will cover:

1. Antennas of non-resonant length.
2. Line attenuation.
3. The transmatch.
4. The balun.

We'll combine these four ingredients to produce simple but effective antenna systems ... the EASY WAY.

First, antennas of non-resonant length:

Quit worrying about them. Some 4,000 commercial broadcast radio stations (and a few hams) use antennas with non-resonant dimensions. The broadcast station must operate with specified radiation pattern and efficiency, reaching the greatest possible number of patrons without causing interference to other broadcast stations. The antenna height required to do such a specific job is seldom a resonant height ... which means that the antenna is invariably non-resonant, but it is generally fed with 50-ohm coax ... how do they do that?.

That's right, they use a "transmatch." That's what you'll find in that little house at the tower base. Just like any other transmatch, its input looks like 50 ohms to the coax, and its output is adjusted to the complex antenna impedance. The circuit used is generally a "T" or "Pi" network, just as in currently available ham tuners .... except that, since the broadcast station uses only a single frequency, the network is "fixed-tuned."

Closer to home, most of us who are mobile on 2 Meters use a 5/8-wave whip and find it more effective than a quarter-wave whip, but the quarter-wave is a resonant length and the 5/8 is not! However, our 50-ohm coax sees a proper load, thanks to matching at the base, so our transmitter happily dumps optimum power into an antenna SYSTEM, which includes a non-resonant antenna that efficiently radiates all the power delivered to it ... Just a couple of examples demonstrating why you don't have to worry about antennas of non-resonant length. You just need a resonant antenna SYSTEM, consisting of antenna, feedline and a matching device.

Second, line attenuation:

If we are going to use a non-resonant antenna, a feedline and a matching device, obviously there will be some standing waves and reflected power to manage. The point here, though, is that on the HF bands it is usually much less of a problem than we think it is. To evaluate this statement, we need four ingredients:

1. The frequency.
2. The type of feedline.
3. The length of the feedline.
4. The feedline attenuation specification.

To demonstrate how these ingredients are used, let's go back to Jim Fisk. Remember, he said that 100 feet of RG8U, at 4 MHz, feeding an antenna with an SWR of 10:1 resulted in less than 1 dB more loss, compared to a perfectly matched line. He got this information from two readily-available sources:

1. The coax manufacturer's specs showed him that RG8U, at 4 MHz, feeding a perfectly-matched load, will suffer a loss of 0.3 dB per 100 feet.

2. Using this information, he consulted a graph on page 82 of the "ARRL Antenna Book" (page 3-12 in the newest edition). This graph shows increased loss with SWR, compared with loss into a perfect match. Jim took the 0.3 dB, which appears at the bottom of the graph, along the horizontal axis, and projected vertically to intersect the 10:1 SWR curve. From this point, he projected left to the vertical axis, where he read "additional loss" of just under 1 dB.

A much more informative chart will give you the above in more comprehensive fashion if you have available the December, 1974 *QST*, containing Chapter VI of Walter Maxwell's seven-part series, "Another Look At Reflections" ... plus, it will properly explain the manner in which "rereflection" takes place. This phenomenon seems to be one of the difficult things to understand, and believe ... but, until you do master it, you will remain puzzled as to why all of that reflected power isn't lost. If you can't find that issue, let me know of your problem and I will be glad to help ... it is of the utmost importance.

So far, we have considered only coax ... and it is quite important to this discussion that we also cover balanced open-wire line. This category includes 600-ohm bare line, plastic-coated ladderline and 300-ohm twinlead, all featuring three advantages:

1. Much less loss ... as little as 10% of that with coax.
2. Handles much higher voltages without breaking down.
3. Tunes the antenna system over a much broader frequency range.

Let's look at that third advantage. I will use, as an example, an 80-meter dipole, resonant at 3750 kHz (the middle of the band):

If I use coax, a transmatch will allow me to cover all of the 80-meter band, presenting 50 ohms to the transmitter on any frequency from 3500 to 4000 kHz ... but for coax, that's about the limit. If I tried to use this same antenna on 40 Meters, it would not be unusual for the 80-meter antenna to present an impedance of 4000 ohms. Using coax, I would find the SWR by dividing 50 into 4000, indicating an SWR of 80:1! The transmatch could not handle this, nor could the coax, which would be subjected to abnormally high voltages and high attenuation losses ... maybe you have found that your transmatch, when using coax, would not tune a particular antenna or frequency — now you can see why ... but don't give your transmatch away — that's not the problem. Let's take that same antenna with the 4000-ohm impedance and see what happens with balanced twinlead (say, 450-ohm ladderline): Now, the SWR is 4000/450, or less than 9 to 1. which any good transmatch can handle very easily ... and, what is even more important, attenuation losses are negligible and voltage breakdown is no longer a problem. The result is that you can use your 80-meter dipole, not just for 80 and 40 Meters, but on all the HF bands (except 160 Meters, which requires a bigger antenna), with high efficiencies everywhere. Of course, as you go higher in frequency, an 80-meter dipole will become more directional, forming a cloverleaf pattern as you get up to 20 Meters and, finally, becoming more directional off the ends of the dipole as you get up to 10 Meters ... but these patterns are not all that clearly defined, and you will be surprised at the DX you can work up there.

Thus far we've talked about (1) not worrying about antennas of nonresonant length and (2) putting line attenuation in perspective, bringing us now to:

Third, the transmatch:

Before we get into the transmatch proper, let's review that part of basic AC theory which says that when the internal impedance of the generator is equal to that of the load, maximum power will be transferred from the generator to the load.

You can regard your your final amplifier as an AC generator (tube or transistor) which, in order to transfer maximum available power into a load, must see an impedance we call the optimum load impedance (not the same as internal impedance. The network in the output circuit of your transmitter is actually a limited range transmatch, built within the transmitter for the purpose of matching the amplifier to the load.

Actually the Pi net will tune the amplifier to other impedances. When working into a feedline that presents something other than 50 ohms, just tune for a plate dip (using low power) and when that dip is as deep as usual, you are matching the rig to the antenna and transferring power to the antenna ... so the Pi net serves as a transmatch and, if it cannot match some widely-differing feedline impedance, then the transmatch you use externally is simply extending the range of the transmatch in your rig. Many of the older rigs had all of this included inside, because back there in "BC" (before coax), there were many more antennas with widely-varying impedances for the transmitter to look at (the Zepp, for example). In either case, though, all we're trying to do is match the generator to the load ... and how does that fit with MYTH #1... "a transmatch just fools the transmitter?"

If you were using only the Pi net inside the transmitter to do the matching, would you then say, "the transmitter is just fooling itself?" Or if you're using a transformer to match a low-impedance mike into your rig's high-impedance mike input, would you say, "the transformer is just fooling the mike?" In each case we are talking about the same thing: impedance matching.

Generally, the load presented to the trans-

mitter by the feedline is not 50 ohms, nor is it purely resistive. Rather, it is a combination of resistance and either inductive or capacitive reactance. Inductive reactance is positive, or a "plus J factor" in the complex impedance. Capacitive reactance is a "minus J factor." Therefore, when the input impedance of the feedline is not purely 50 ohms resistive, it might be 100 ohms of resistance and 50 ohms of inductive reactance. In the vernacular of feedline mechanics, we would call this "100 plus J50." It is the job of the transmatch to take an impedance like this and provide an interface between it and what the transmitter sees when looking at the other end of the transmatch. When each end of the transmatch is matched to what it's connected to, the antenna load is properly matched to the source and maximum power is transferred to the antenna SYSTEM. Of course, when maximum power is transferred out of the amplifier, minimum power remains to be dissipated internally — bringing us to MYTH #2, which is: "Reflected power gets back into the amplifier, overheating the tubes, etc." ... NOT SO! Heating is the result of an impedance mismatch, with less than optimum power getting out of the amplifier, and too much power REMAINING IN THE AMPLIFIER to be dissipated as excessive heat ... all the amplifier wants is a proper impedance match. It wouldn't recognize SWR or reflected power if you introduced them!

MYTH #3 goes something like this: "but look at all the power I'll lose in that transmatch ... and the fellow who said that probably has a low-pass filter at the output of his rig ... a small box packed full of small coils and fixed capacitors which, the manufacturer says, introduces loss of less than 1/4 dB. Well, a transmatch is a larger box, containing one large silver-plated coil and two large wide-spaced air-dielectric capacitors ... no resistors to consume power. Since the actual ohmic resistance in the transmatch is negligible, you lose very little power in that box.

Here's how the transmatch works: Let's continue with that example of "100 plus J50" ... and let's use the popular "T" circuit for our transmatch. This circuit consists of two air-variable capacitors in series, with a variable coil connected between the junction of the two capacitors and ground. The antenna feedline is connected to the free end of one of the capacitors and the transmitter is connected to the free end of the other capacitor. Manipulation of the transmatch is simple: First, set both capacitors halfway open. Then, with the receiver operating, adjust the variable inductor for the strongest received signal ... this puts you in the ball park. Then, applying low power, alternately juggle the two capacitors back and forth, exactly as you juggle the "plate" and "load" controls on your rig, until you see maximum power output and minimum SWR at the same time, both being measured between the rig and the input to the transmatch. It is important that you use the minimum amount of inductance necessary, thus assuring maximum efficiency. After getting tuned up like this, what have we done? ... Remember, the tuner output is looking into "100 plus J50." Therefore, if we were to disconnect the feedline and put a bridge on the output terminals of the transmatch, we would measure "100 minus J50," the conjugate of the feedline impedance. Now reconnect the feedline to the transmatch. With conjugate impedances looking at each other, the plus and minus J factors cancel, leaving only 100 ohms, resistive ... but the transmitter wants 50 ohms, resistive, so the input capacitor combines with the shunt inductor to perform an impedance match, bringing the 100 ohms down to 50.

Of course, since the shunt coil is shared by both input and output capacitors, there will be some interaction and both capacitors must be juggled alternately for optimum tuning. This is all much simpler than it sounds and takes less time to accomplish than I have taken to tell about it. When you have become accustomed to your transmatch, this all happens in a few seconds. Also, you should log the transmatch settings for favorite frequencies. Tuning is fast thereafter.

Fourth, the balun:

If you have a transmatch that includes a good husky balun, and if you plan to use balanced open line, you have no problem; if you are using coax, no transmatch, a balun at the antenna, and are staying well under 2:1 SWR, with modest power, still no problem ... but let's take the fellow who has an 80-meter dipole, cut for the middle of the band (3750). He tries it first without a balun ... SWR is low at resonance, but around 7:1 at the extreme band edges. Next, he puts a 1:1 ferrite-core transformer-type balun up at the feedpoint of the

antenna. What happens? His SWR comes down to 1.5:1 at the band edges. Boy, that balun really solved the problem. Right? ... WRONG!

In this case, if his rig would load up (or if he used a transmatch), he would be much better off without a balun. You see, that antenna hasn't changed at all. The SWR is still just as high as ever ... but he thinks his SWR came down ... Didn't his meter say so? Yes, it did, and that's just the point. The meter is reading less reflected power, all right, because the high reactive currents on both sides of resonance are being absorbed in the balun's ferrite core. That means that both radiated and reflected power are down, making the meter read lower in the reflected power mode. This fellow could carry this a step farther ... He could replace the ferrite balun with a 50-ohm resistor ... as Walter Maxwell says, "low SWR can kill you!"

This is not a blanket condemnation of transformer-type baluns ... Used correctly, they are often helpful and necessary, but you need to know from experience how basic types of antennas should work, so that when you run into one such as I have described here, you don't rejoice and assume that you got something for nothing ... instead, worry about what's wrong! There are two considerations when using transformer-type baluns:

1. Operate them well within their power ratings (there are some transformer-type ferrite baluns rated at 3kW, 5kW and even higher).
2. Don't operate them in the presence of high SWR.

To operate all the way across several bands, handling widely varying impedances and SWRs, you need either the husky balun provided in a good transmatch or, even better, a well-designed coaxial balun.

It is beyond the scope of this talk to cover coaxial baluns properly, but I have a wealth of good information on the subject and will be happy to send it, following your request. Whatever kind of balun you use for balanced open line should be 4:1 or higher. It is quite practical to put the balun just outside the shack, terminate the balanced line there, and come into the unbalanced transmatch input with 10 feet or less of coax. This is convenient and simplifies switching antennas.

Now we have discussed the four ingredients:

1. Antennas of non-resonant length.
2. Line attenuation.
3. The transmatch.
4. The balun.

This brings us to the "bottom line" ... THE EASY WAY. What I have been leading up to is the suggestion that we tune our antenna systems at the other end of the feedline ... IN THE SHACK. To nail this point down, let us listen again to Walter Maxwell, who starts first with a few philosophical comments, then follows with some hard, practical applications. Here is Mr. Maxwell:

"Before going further, the reader may ask, 'why match at the input?' The answer is that without matching at the feedline input we have very little operating flexibility. In the absence of a line-matching network we are restricted to operating in a narrow part of the band (especially on 80 Meters) unless effective measures for broadbanding the antenna have been taken.

"We are restricted because, as we deviate from the antenna-resonant frequency, a resulting increase in feedline-to-antenna impedance mismatch is transferred to the line input as an increased transmitter-to-feedline impedance mismatch. As a result, the transmitter load impedance varies beyond acceptable limits, the transmitter fails to load properly, and it can be damaged by arc-overs caused by underloading. These phenomena (plus unawareness of the remarkable performance capability of line matching) are largely responsible for the traditional low SWR mania. On the other hand, simple impedance matching at the feedline input provides stupendous improvement in operating flexibility because the line matching network compensates for the impedance changes at the feedline input, and provides the correct load impedance for the transmitter, at whatever frequency we select within an entire band. Correct load impedance is obtained by simply adjusting the network, at the operating position.

"So, the next question is: 'Why not broadband the antenna and avoid retuning a matching device when changing frequency?' The answer is that we can, but only to a limited degree ... because, for example, the typical techniques which would permit coupling the

average amateur transmitter directly into the feedline over the entire 80-meter band (with no adjustments other than retuning the transmitter) are not practical in the average amateur setup. This includes the coaxial dipole (sometimes called the double bazooka) which, contrary to prevalent opinion, fails to deliver any significant bandwidth improvement over a simple dipole when it is fed with the usual 50-ohm feedline." NOTE: Documentation of this startling statement is available from this writer.

And now Mr. Maxwell practices what he preaches:

"First, in the Tiros-Essa weather satellites, of which the entire multifrequency antenna-system design was the work of the author, the dipole terminal impedance at the beacon-telemetry frequency of 108 MHz was 150 – J100 ohms, for a VSWR of 4.4, reflected power 40%. Matching was performed at the LINE INPUT, where it was fed by a 30-milliwatt telemetry transmitter (we can't afford much power loss here!). The feedline and matching network attenuation was 0.2 dB, and the additional loss from SWR on the feedline was 0.24 dB (5.4%), for a total loss of 0.44 dB (9.6%).

"On the prevalent but erroneous assumption that all reflected power (40%) is lost, only 18.1 milliwatts would reach the antenna, and efficiency, determined on the same erroneous basis, would be only 60% ... But 27.1 milliwatts were measured! Of the 2.9 milliwatts lost in total attenuation, only 1.6 milliwatts of it was from the 4.4:1 SWR! So the real efficiency would have been 95.5% if perfectly matched at the load, but it reduces to 90.4% by letting the 4.4 VSWR remain on the feedline. The second example was the Navy Navigational Satellite (NAVSAT), used for precise position indications for ships at sea. The antenna terminal impedance at 150 MHz was 10.5 – J48 ohms, for a VSWR of 9.8, reflected power 66%. This one was also matched at the line input, where flat line attenuation was 0.25 dB, and the additional loss from SWR was 0.9 dB, for a total system loss of 1.15 dB, approximately 1/6 of an "S" unit. This was an insignificant amount of loss for this situation, even in a space environment where power is at a premium. Why did we match at the line input? ... Because critical electrical, mechanical and thermal design problems made it impractical to match at the antenna.

"Line matching provided a simple solution by permitting the matching elements to be moved to a non-critical location. This design freedom afforded tremendous saving in engineering effort with negligible compromise in RF efficiency, in spite of SWR levels many hams would consider unthinkable."

Walter Maxwell's experiences give you the real thing, not just opinions, and I hope you are beginning to believe that what I am talking about REALLY WORKS ... I have been doing it "the easy way" for some 10 years. It's been a long time since I walked through rain or snow to adjust a tuning capacitor at the base of my tower, change a clip lead or change out a remote-tuning motor that gave up the ghost during a critical QSO! I use an 80-meter dipole at 65 feet, 450-ohm balanced line and a transmatch, performing with high efficiency from 3.5 to 29.9 MHz.

My "folded umbrella" is a seven-band folded unipole using 450-ohm line and a transmatch, showing 50 ohms (R) to the rig on all HF frequencies. The antenna proper is resonant at 1.9 MHz, but it works DX on all bands. It's also a bonus for general coverage receivers and the new WARC bands.

At my desk in the shack I have a 3kW transmatch. Under the glass desktop I have logged all pertinent transmatch settings, across all appropriate bands and for each antenna. Most hams today enjoy all the conveniences afforded by broadband "no-tune" rigs, memories, scanners, computer controls, etc. ... so it seems quite strange that we should be content to remain in the dark ages when it comes to tuning our antennas. Believe me it is a real pleasure to be able to do it all at your desk.

What kinds of antennas can we tune this way? Actually, just about any kind. A ham friend called me, saying that he had a 60-foot tower with beams on top and had put a gamma rod down the side. I asked him to try feeding it with 450-ohm line and a transmatch. I worked him later that evening ... he was S9 on 160 Meters and a bit stronger on 80 Meters ... and he was barefoot from Indiana (I was near Dallas).

I have tuned delta loops, quads, zepps, ground-plane verticals and others. However, don't expect instant success every time. For instance, if you want to employ a multiband antenna, there will be an optimum length of feedline which gives the best compromise in SWRs across all the bands. An 80-meter dipole will tune up most easily on all frequencies if your feedline is approximately a quarter-wavelength at the lowest frequency used (any odd multiple of this length works the same). Depending on the environment, this length will vary slightly, but it is not critical, and some "cut-and-try" will get it just right. Now let's review what we've been talking about:

First, realizing that I needed "third party credibility" to support me in presenting a controversial subject, I quoted Jim Fisk, Walter Maxwell and Walter Anderson ... with their "endorsement," I developed four "axioms":

1. Don't fear antennas of non-resonant length.
2. Put line attenuation in proper perspective.
3. Understand and trust the transmatch.
4. Know what you can and cannot do with baluns.

I promised that all of this would add up to "THE EASY WAY."

I hope this has brought you something of value ... I realize how difficult it is to change a concept that has been maturing for years ... I have only to tune in the 75-meter phone band late at night to remind myself that, as Dale Carnegie says, "A man convinced against his will is of the same opinion still!"

Walter Maxwell says it best ("Another Look At Reflections":):

"Although reader response to this series of articles has been excellent, some have told the author, 'Your story is interesting but you'll never convince me that I won't get out better with a perfect 1.0:1 SWR.' Now any reader who still entertains any skepticism of these entire proceedings concerning SWR is reminded that the information presented herein is not simply a recitation of the ideas or opinions held by the writer, but has been taken from the professional and scientific literature and has been paraphrased specifically for the radio amateur with great care not to change the meaning; moreover, in striking contrast to the many differing opinions heard on the subject during amateur discussions there are NO SUCH DIFFERING OPINIONS AMONG THE PROFESSIONALS (including textbook authors), because the principles involved are completely understood and based on true scientific facts, which are not subject to divergent opinions as found in politics or religion."

ANTENNA TERMINOLOGY REVISITED

In connection with antennas, there are some very basic terms which still continue as subjects of controversy. I hear these points discussed, enthusiastically, during on-air conversations, and it certainly doesn't sound as though general agreement on proper interpretation of the terms has yet been reached, so please bear with me as we review old axioms and try to reconcile differing opinions. In so doing, we will examine these three terms:

1. Radiation resistance.
2. Feedpoint impedance.
3. Radiation efficiency.

Much of the misunderstanding which interferes with our grasp of these terms is really based on semantics. We often get to a point in these discussions where we suddenly discover that we both are thinking the same but saying it in different words. This happens because, in everyday applications, we slip away from the precisely descriptive terms and lapse into the colloquial. We still know what we mean, and we assume that the other guy does, too, but because we are taking too much for granted, the other guy does not interpret our casual statement the way we think he should and that's where the disagreement begins.

So, this will be an attempt to take these three basic terms and define them precisely enough to clear up the misunderstandings. I am fully aware that this is a presumptuous undertaking, and I won't be too surprised if your verdict is less than unanimous ... but let's give it a try, starting with "radiation resistance:"

We'll use a conventional half-wave dipole as the medium with which to form our mental picture of radiation resistance. Now, when we deliver power to this antenna, some small part of it is lost as heat developed in the ohmic resistance of the wire, although this loss is normally very small. Generally, most of the power will be radiated usefully and, since this power is actually doing work, it must be dissipated in some kind of resistance, but we don't see any other kind of physical resistance. So what is it? Well, this resistance that we can't lay our hands on is actually in the impedance of free space, into which we are transferring power. This free space impedance has been determined to be 377 ohms.

The radiation resistance of our antenna is considerably less than this, so there is an impedance mismatch between the antenna and free space, but we do transfer power nevertheless, and if we can measure the power actually radiated and the current flowing in the antenna, then we can can insert those values in the simple formula: Power = Current squared x(times) Resistance. An accurate field-strength meter will measure the radiated power and an RF current meter will show the current flowing in the antenna. By substituting those values in the formula, we solve for "R." That "R" is called the "Radiation Resistance." For the ideal half-wave dipole in free space, it's approximately 73 ohms. The current we measure in the antenna is measured, of course, at the point of maximum current flow, known as the "current loop," and the resistance is properly known as "loop radiation resistance," although, in practice, the word "loop" is most often omitted but implied — one of the reasons we slip into the problem of semantics.

Now, if this dipole uses a good conductor, such as copper, typical loss resistance of the wire at a frequency of 14 MHz would be on the order of one ohm, so the feedline looks at this, plus the 73-ohm radiation resistance, for a total of 74 ohms. This means that 73/74 of the power delivered to the antenna is radiated usefully into space. The amount of power lost in the wire will vary, of course, depending on wire size, frequency and length of the antenna wire. In practice, a reasonable wire of, say, #14 or #12 would result in loss that would not be noticeable at the other end of the circuit.

Next, we'll look at "Feedpoint Impedance." Now, remember that our "Radiation Resistance" was measured at the point of maximum current in the antenna, or the "current loop," and that is the only place we can measure radiation resistance. But "feedpoint impedance" can be measured wherever we decide to feed the antenna. The values of radiation resistance and feedpoint impedance can, therefore, be very, very different from one another although, in a resonant antenna, they are both resistive. For example, the half-wave dipole can

be fed at the end. This is known as "voltage feed," and this "feedpoint impedance," or "input impedance," is very high (but "loop radiation resistance" at the center is still unchanged). For "voltage feed," input current is low, but the high impedance means high voltage, so the product of high voltage times low current will result in the same amount of power being delivered with "voltage-feed" (at the end) that we delivered at the center with the product of high current times low voltage.

The important thing to remember here is that, no matter where you feed the antenna, the current loop remains at the center (using the basic half-wave dipole), determining radiation resistance. Perhaps one of the reasons for confusion of these terms is that we seldom feed a half-wave element anywhere but in the center ... and, at this point, radiation resistance and feedpoint impedance are virtually identical ... so we get used to thinking of them interchangeably. After that, it's easy to imagine how the two terms can get switched.

The third term is "Radiation Efficiency" or "Antenna Efficiency." This is probably the easiest of the three terms to keep straight. It is just the ratio of radiated power to the amount fed into the antenna. For example, if the feedline delivers 100 watts to the antenna and it radiates 95 watts, the radiation efficiency is 95%. However, it is necessary to go a little further in arriving at which part of the system is responsible for the losses contributing to the efficiency figure.

The antenna load which the feedline sees actually consists of three resistances in series:

1. The loop radiation resistance, representing power that is usefully radiated.
2. The AC resistance of the antenna wire, plus any other ohmic losses resulting from the mechanical makeup of the antenna.
3. A resistance representing environmental influence of the ground and other nearby conducting surfaces external to the antenna.

That third resistance, mainly ground loss, typically, is a major obstacle to the attainment of high radiation efficiency ... so how do we cope with that, for both vertical and horizontal antenna types?

1. For the conventional quarter-wave vertical, ground losses are of the greatest concern. When you feed such an antenna at the base, remember that half of it is what you have in the ground ... and remember also that your feedline sees, in addition to the radiation resistance and the ohmic antenna losses, the ground losses. In calculating efficiency for the vertical, one of the three resistances across which input power is developed is a value representing power lost in the ground. You can't measure this resistance with an ohmmeter any more than you can measure radiation resistance, but it's there just the same and it consumes power that never gets radiated ... so your feedline sees all three in series: radiation resistance, plus ohmic resistance, plus ground loss resistance. For example, let's use a short vertical, with a radiation resistance of five ohms, ohmic resistance of one ohm and ground loss resistance of 15 ohms. Thus, the feedline sees a total of 21 ohms, but only the five-ohm radiation resistance develops usefully radiated power, so the efficiency of this antenna is 5/21, or 23.8%. This kind of efficincy is typical of a short vertical, but it can be improved considerably with toploading, which will take the current concentration at the base and distribute it more equitably up the antenna, thus diminishing ground losses (because the current returning to the base through the same ground resistance is less). This will improve radiation efficiency and, of course, the more radials you can put in the ground, the fewer the ground losses and the higher the radiation efficiency.

2. Now the horizontal antenna: If this antenna is one half-wave or more above ground, ground losses will be negligible. Therefore, if we use, say, the 40-meter band as an example, and the antenna wire is #14 to #12, the ohmic resistance of the wire will be negligible and, with over 70 ohms of radiation resistance, the efficiency will be well over 95%.

Comparison of the efficiencies of these two types gives a clue as to why the horizontal 1/2 wave dipole is so popular and why they say "a vertical is an antenna that radiates poorly in all directions," but don't let that quote be the final word. That statement is not true of a properly installed vertical antenna system. You cannot just put up a vertical with no ground system and expect it to work well, any more than you could expect an inverted vee to work with half of it chopped off.

Furthermore, the ideal high-efficiency dipole I have described here is the exception rather than the rule. A much more typical setup is an inverted V on 80 Meters, with the

apex at 25 or 30 feet.

In this case, ground losses are extensive and a vertical with a good ground system would compare favorably with a low dipole. The main difference would be in the radiation angle. The high angle from the horizontal dipole would be more effective at short range, whereas the vertical would outperform the horizontal on DX.

Summarizing, we had another look at three basic antenna terms:

1. "Loop Radiation Resistance" or "Radiation Resistance," which is a value equal to that of a resistor which would consume an amount of power equal to that radiated by the antenna.

2. "Feedpoint Impedance," which can be low, high or in between, depending on where the antenna is fed. It can be virtually equal to "radiation resistance" if the antenna is fed at a current loop ... but it is not to be confused with "radiation resistance," since it can be a very different value when the antenna is fed at other than a current loop, and even though the feedpoint is at other than a current loop, the "loop radiation resistance" and the value of the current at that loop will remain unchanged.

3. "Radiation Efficiency," or "Antenna Efficiency" is the ratio of useful power developed across "radiation resistance" to the total power developed across "radiation resistance" plus "ohmic resistance" plus "loss resistance" (mostly ground resistance).

FEEDLINE TERMINOLOGY REVISITED

As was the case regarding the semantics involved in antenna terminology, we will now apply the same treatment to feedline terminology, using just the basic terms and, again, because we frequently take the meanings of these terms for granted, we often end up misusing them. Although such misuse is unintentional, the end result may be a lack of agreement that could well persist until all terms are properly defined.

This discussion will be devoted to a clear definition of each of five basic terms:

1. Current.
2. Charge.
3. Power.
4. Energy.
5. Reflected power/energy.

First we want to be sure that we really understand each of these terms. Next, we want to establish the relationship between the terms ... and finally, we will use these relationships as tools with which to clarify general and serious misunderstanding of feedline mechanics ... and such misunderstanding often obscures what would otherwise be a clear picture of the process of transferring power from the transmitter to the antenna.

We must examine the first four terms in pairs, since "charge" and "current" go hand-in-hand ... and the same is true of "energy" and "power" ... so let's start with the first pair:

Right away, we get into this semantics thing again, because when you stop to think of it, we talk all day long about "current flow" but is that what we mean? ... does current really flow? If we go back to our basics, we are forced to remember that current does not flow. Current is defined as the rate at which charge flows past a reference point ... so it is charge that flows, not current. You can review this on page 2-2 of the 1982 ARRL Handbook (or in a very similar location in other editions) ... yet, once we leave our studies of basic electricity, getting into more advanced circuitry, we talk about nothing but current flow. We know, of course, what we mean, and we assume that the other fellow knows what we mean, but after we have gotten deeply into a discussion and have been inadvertently careless with our semantics, this is the kind of thing that ends in disagreement and, sometimes, a bit of heat!

Now with that, you can forget about "charge" and "current." We used them only as an example which, however, compares directly with two terms which are very important to this discussion. They are, of course, "energy" and "power."

To develop this relationship, energy relates to power the same way that "charge" relates to "current." We saw that "current" does not flow but "charge" does ... and it's also true that "power" does not flow but flow but "energy" does. Textbooks define "power" as "the quantity of energy passing a point per unit time" ... but after we leave the textbook, we revert to talking about power flowing. We talk (yes, and think) about power flowing up the feedline to the antenna.

When we talk about SWR meters, we at least infer that reflected power is flowing back down the line to be measured. We read textbooks on feedline mechanics and we see "energy flow" and "power flow" used interchangeably.

Just as with "current flow," we know what is meant but we take it for granted. Unfortunately, not everybody does! The result is that at least one writer in a national magazine has taken the term "power flow" as though it were literally true, and made a believable case for the proposition that reflected power is fictitious.

I particularly wanted to touch on this item because this fellow had me believing his story for a time. However, thanks to Walter Maxwell, I became aware of the fallacy in that presentation ... and Walter has a short piece in *QST* for February, 1983, which completely clarifies this point, but you can see how this other writer could think (thereby making you think) that reflected power is fictitious, simply by hewing to the strict definition that power does not flow ... and then saying that since power does not flow, reflected power is fictitious.

This same writer challenged several other proven textbook principles of transmission line theory ... and what made it confusing was that his definitions of "power" and "energy" were correct ... but the manner in which he used them was incorrect, and very misleading.

First, before we examine these misinterpretations, let's look at some textbook-correct facts:

1. Voltage and current components of the forward wave on a transmission line are always in phase.

2. Voltage and current components of the reflected wave are always 180 degrees out of phase with each other.

3. Combining the above components of both forward and reflected waves will result in voltage maxima and minima of the resulting standing wave always being displaced from the respective current maxima and minima by a spacing of 90 degrees. The important thing here is to distinguish between the standing wave and the combination of forward and reflected waves which slide past one another to produce that standing wave. An effective picture of this complex action can be had by dropping a stone into a swimming pool. First, you will see the original incident wave travelling toward the side of the pool; then, you will see that wave strike the side of the pool and return as a reflected wave; here, you can see the two waves, forward and reflected, move in opposite directions at the same time; and, finally, you can see peaks and troughs which do not move in either direction. These are the standing waves which result from combining the components of the forward and reflected waves.

Now, getting back to standing waves on the feedline, let me say again that the resultant standing wave plots of voltage and current are always separated along the line by a distance of 90 degrees ... and it is emphasized that this distance between the plots contains no phase information ... but at every point where either the voltage or the current standing wave is minimum, the phase angle between line voltage and current is exactly zero degrees. At points in between, the phase angle may vary between zero and 90 degrees, depending on the extent of the mismatch, but reaching 90 degrees only when the mismatch results in total reflection of power ... an infinite SWR, in other words.

And, bearing these textbook facts in mind, here is the fallacy in the reasoning of at least two nationally-published authors: They incorrectly assume the 90-degree spacing between the maxima and minima of standing wave voltage and current to be a 90-degree phase relationship.

Once this fallacy can be established, it is a simple matter to point out that, since power factor is equal to the cosine of the phase angle (and the cosine of 90 degrees is zero) then, since real power is equal to power factor times voltage times current, it follows that zero times anything is zero! Therefore, reflected power is fictitious!

A very neat package indeed if they hadn't mistaken the 90-degree spacing for phase information ... so their house was built on a foundation of sand and collapsed when faced with textbook facts ... but this demonstration of how easily we can be misled should cause us to be wary of neat, pat solutions for complex problems.

The real truth is that reflected power (or energy) is as real as the power delivered to the line by the transmitter, or the power radiated by the antenna. This can be proven in various ways. There are many mathematical, analytical tools, but most of us simply do not have the training to use them. There is one simple laboratory method, though, which provides easy-to-understand proof: It is based on the fact that wave energy which is not absorbed by a mismatched line termination can be separated from the forward wave and dissipated in a temperature-calibrated resistor which will give an accurate reading of the amount of real power in the reflected energy wave. Obviously, if the reflected energy were fictitious, no heat would be generated — but the point is that heat is generated!

Here's an analogy which should make it easier to believe that reflected power is real: Remember that light waves are of the same family as radio waves, differing only in wavelength. Next, it should be obvious that a mirror would offer a highly reflective termination for the light waves. That being the case, if that reflected energy were not real, would you see your image?

I wanted to tie this talk on feedline termi-

nology to our previous coverage of antenna terminology. To do this, I began by using the terms "charge" and "current," establishing their relationship as an analogy to what followed. Then, the similar relationship between "energy" and "power" was developed. Finally, I concluded with proof that "reflected power" is indeed real, a direct contradiction of incorrectly-documented and nationally-published articles dedicated to the proposition that reflected power is fictitious.

How can I be so confident of my material in the face of such apparently formidable statements to the contrary? ...

Easy! ... I learned it from Walter Maxwell, and all you have to do is turn to pages 52 and 53 in the February, 1983 *QST*. Not only does he expand the subject with complete authority ... he provides you with an excellent set of references, including the incorrect ones which I have been discussing. However, before you read Maxwell's article, I must tell you that in rushing to meet the February deadline, *QST* unfortunately went to print without having Mr. Maxwell correct the final proofs. As a result, there are three tiny bobbles. As luck would have it, though, any one of them could change the entire meaning of the article ... so let me point these out very carefully before you read the article:

1. Page 53, column one, last paragraph, beginning with "Another reason many amateurs believe ... " Now, count down to the 14th line, where it says "angle between voltage and current" ... that should read "angle between line voltage and current."

2. At the end of that same line 14, and continuing on line 15, is an "editor's comment," inserted in parentheses. Cross this out ... it is wrong and would be confusing.

3. In the next to the last line of the article, in column 2, page 53, there is a formula for "watts per unit area." The sub-script for "E" is correct, but the sub-script for "H" should have the negative sign above the positive sign. Otherwise, the sub-script for "Z" could not be as shown (and it is correct).

These corrections were made in a subsequent issue, but I thought this way of bringing it to your attention would be convenient for you. I know this is not easy to grasp the first time around, so read it again very carefully, and read Walter's article, pages 53-54, *QST*, February, 1983.

BALUNS

Most amateurs believe that a 1:1 balun will achieve a 1:1 match between feedline and antenna. This is often a mistake, because "1:1" signifies only the output-to-input impedance ratio of the balun itself. This means that when the transmitter looks at the input side of the balun, it is going to see 50 ohms only when the antenna is 50 ohms. If the antenna impedance varies greatly from 50 ohms, not only will the balun impedance vary, but other undesirable things will happen, as we shall see. However, understandably, many amateurs believe that the balun is performing an impedance transformation function because the VSWR is sometimes reduced dramatically. For example, on the 75-meter band, a dipole which is resonant in the center of the band should show a VSWR of well over 5:1 at the band edges ... but a ferrite-core balun, used at the feedpoint, may show the transmitter a VSWR of less than 2:1 over the entire band. This should cause suspicion that something is wrong!

What is wrong is that, in many cases, losses in the balun will be encountered on either side of resonance. In such case, much of the reflected power which would have been observed at the VSWR meter when not using a balun can no longer get back to the meter, since some of it has been absorbed in the ferrite core.

Also, contrary to what many think, most of that reflected power would be effectively radiated if the balun had not soaked it up. Without the balun, only a negligible amount of power would have been lost, this due to line attenuation, and it would be a mere fraction of a dB ... so, although the unsuspecting may be congratulating himself on low VSWR, this would be low VSWR for the wrong reason! ... or, to look at it another way, more power would be radiated from an antenna with a VSWR of 5:1 and no balun, than would be the case if a ferrite balun were used.

What would be happening if that balun is husky enough to handle all the power without saturating? In this case a more realistic VSWR would be seen at the transmitter ... if the balun has no significant leakage reactance. However, many baluns do have considerable leakage reactance, a problem which can also interfere with a true impedance transfer. Depending on the polarity of the leakage reactance, relative to the polarity of the antenna reactance, impedance transfer can be either more or less favorable, which further points up the fact that the balun isn't often a simple panacea ... and, even with no balun, we may not read true VSWR, depending on the length of the coax, because of antenna current on the outside of the coax. Also, under the most ideal conditions, VSWR at the transmitter will be slightly lower than at the antenna, because a small amount of reflected power is lost to line attenuation.

This adds up to the practical requirement for you to know what value of VSWR to expect on the antenna alone, minus the balun, for a given set of conditions. Practical knowledge on this subject comes from a combination of experimenting and experience. A ham said to me, "Say, every antenna you put up seems to work well." My answer was, "I just haven't told you about the others!" In this vein, there is one basic rule to remember: Don't assume that low VSWR necessarily indicates a good antenna.

In particular, distrust VSWR that remains quite low over a considerable range of frequencies, unless that antenna is specifically of broadband design. For example, if it is just a half-wave dipole on 75 Meters and the VSWR is low over the whole band, start looking for what is wrong.

Basic construction of typical baluns is covered in any of the ARRL Antenna Books. Also, if you have seen the series in *QST* by Walter Maxwell, entitled "Another Look At Reflections" (7 articles, 1973 through 1976), you'll remember that it is a magnificent presentation of many facets of antenna and feedline design principles. You will find me referencing Mr. Maxwell frequently. His theme is that he is telling you nothing new or different ... just basic common sense principles which need a lot of repeating in order to offset the "old wives tales" and superstitions which haunt the ham bands.

At this point, I may have left you skeptical about baluns and you may have a somewhat

negative impression ... but that's not all. We can call that the "bad news" ... now, for the "good news:"

For this good news, we can thank George Badger, W6TC, of EIMAC (a colleague of Bill Orr, W6SAI). George wrote a two-part article in February and March, 1980, for *Ham Radio Magazine*, which is a most comprehensive collection of information on one specific class of baluns. (Later in this chapter there will be other, more recent good news about a different type of balun, courtesy of Walter Maxwell).

George starts out with some background. He points out that, at RF, due to inevitable leakage reactance, narrow-band tuned transformers are often used, but that, for many applications, bandwidth is too narrow. Also, quarter-wave matching stubs may be used but they are also narrow and are usable at or near just one frequency. The emergence of solid-state RF power devices has, in many instances, made the narrow-band transformer virtually useless, and the broadband transformer, made possible by the development of ferrites, has come into its own. Until this happened, users of transmission line transformers were caught between two extremes:

1. Low frequency response falls off if you don't have enough turns in the coil, since inductive reactance reduces with decreasing frequency.

2. If you provide more turns to improve the low frequency response, then distributed capacity between the coil turns is increased. Of course, the higher the frequency, the lower the capacitive reactance, so the falloff at the higher frequencies means that increasing the inductance to boost low frequency response is self-defeating.

Ferrite cores solve both of these problems by making fewer turns of wire look like a lot more inductance, thus improving <u>both</u> low and high frequency response. As a result, broadband transmission line transformers and baluns have become very popular with hams. However, while this principle is very useful, there are, in some instances, attendant disadvantages. There are many applications where the ferrite core is unbeatable, but others where it is definitely not recommended. In general, the distinction between the two categories is dependent on the amount of power used.

We hams buy or build linear SSB gear and use effective low-pass filtering to avoid TVI. Then we turn right around and combine our harmonic-free signals with we-know-not-what, as we pass them through ferrite-core transformers and/or baluns in our antenna systems.

If the core becomes saturated, saturation causes it to become non-linear and a non-linear device is all that is needed to create new and unwanted frequencies. The high-permeability ferrite cores can also be permanently damaged when exposed to excessive power. Just feed maximum legal power into the wrong antenna, and if there is a balun at the feedpoint, that balun may never again do what it was designed for.

On the other side of the coin, ferrites, powdered iron, special steel tapes and other magnetic materials have been a boon to modern circuit designers ... but before using these materials in high-power circuits or antenna systems, we should know:

1. How much power will they handle safely?

2. At what power level will they saturate and become non-linear?

Ferrite baluns and transformers generally use copper wire with thin enamel insulation. It is quite necessary for these wires to be wound tightly on the core, with the turns as close together as possible, to minimize leakage reactance. All too often, this thin insulation is the reason for arcing between turns and/or core when using high power. Those who have blown a balun and taken it apart to examine it know what I mean. Now, let's look at that "good news": George has come up with a family of RF transformers and baluns which feature all these good things:

1. Broad bandwidth.
2. Excellent balance.
3. High power-handling capability.
4. No saturable or non-linear characteristics.
5. Less loss than in ferrite devices.

First, let's look at the coaxial RF transformer: Basically, a transmission line transformer consists of two or more lengths of transmission line connected in parallel at one end and in series at the other end. Then, if you place one volt across the end of two lines whose conductors are paralleled, the end with the series connection will show two volts. Since the impedance ratio is equal to the square of the

voltage ratio, then the impedance transformation is 4:1. This can be a step-up or a step-down ... Depending on the impedance of the line used, the actual impedances can be (a couple standard examples): 12.5 to 50 ohms, or 50 to 200 ohms. Also, to provide isolation and prevent RF current flow on the outer conductors of the coax, these lines must be wound into certain size coils. Sometimes this "choke" action is aided by winding the coax on a magnetic core.

George Badger's two *Ham Radio* articles cover two main areas:

1. Baluns.
2. Transformers.

As his article develops, it becomes apparent that, for some uses, both impedance transformation and balance/unbalance are involved. To satisfy these requirements, George describes a two-stage device, consisting of, for one example, (1) a 4:1 balanced-to-balanced transformer and (2) a coaxial 50-ohm balanced to 50-ohm unbalanced balun.

The two stages are simply joined together to provide a 200-ohm balanced input at one end and a 50-ohm unbalanced input at the other end. One application for this balun is feeding 450-ohm ladderline (balanced) to the unbalanced 50-ohm input of the rig (or a transmatch).

Now, at this point, the perceptive person will be justified in observing "Hey, 450 to 50 ohms is a 9:1 impedance ratio ... what is going on here?" ... and this needs clarification before we move on. First, 450-ohm balanced open-wire line is most often used to feed an antenna which tunes a wide range of frequencies, usually on several bands ... so the impedance of the feedline becomes academic, since the antenna impedance may vary from a few ohms to thousands of ohms.

In this kind of situation, open-wire twinlead has two attributes: (1) a pair of wires far enough apart not to arc over with the often-high voltages which may appear on the line; (2) a pair of wires which will give minimum power loss when subjected to considerable SWR/reflected power. 450-ohm feedline will satisfy these criteria and suffer about 10% to 15% of the loss in coax used in similar situations.

Now, for the 50-ohm/50-ohm balun to be used as the second stage, in conjunction with the 4:1 transformer: To meet this requirement, George uses the time-tested Collins coax balun. He calls it "by far the best balun I have ever used." This balun was first described in a book published by Collins, entitled "Fundamentals of Single Side Band." Strangely, the Collins balun is rarely mentioned in ham literature, which is surprising in view of its superb performance. However, the original Collins version was wound on phenolic tubing and, if made with RG8, became quite bulky but George showed that it could be equally effective if "bunch-wound and much more compact. I use this two-stage balun/transformer, made of RG213, for all antennas with 450-ohm feeders and it is simply the best I have ever found for this purpose. It will be very much worth your while to get these articles. They total over 18 pages and, as I have said, contain more good information on coaxial baluns than you will find almost anywhere.

Although many different types of baluns are described by George, including both single and double-stage types, I am going to give you here some significant numbers for the one I use, sufficient to confirm my claims for it. George worked a balun like this into a precision 200-ohm resistive load, and below, compared to a popular commercial ferrite balun, are the results:

These numbers speak for themselves ... plus the significant advantage of high power capability, with no saturation or non-linearity. To sum this up, advantages of these broadband coaxial transformers/baluns are:

1. Inexpensive.
2. Linear (no saturable materials used).
3. Use readily available material (coax and hookup wire).
4. Relatively compact.
5. Weatherproof.
6. Low SWR.
7. Balanced.
8. Arc-proof.

In the foregoing, we have been looking at the kind of balun needed for high-impedance open-wire tuned feeders. Now, here is one of the latest developments most specifically slanted toward the plain coax-fed dipole, a compact 1:1 balun for use up on the antenna itself. These baluns are, of course, discussed at great length on the air. Questions often heard include:

"Should I use a balun? ... if so, why?"

"Why can't I use both antenna balun and transmatch together?"

"Must my coax be cut a precise length?"

"If not, why is SWR different at various lengths?"

"Will a balun allow antenna impedance to be measured accurately."

"Can we measure antenna impedance accurately without a balun?"

I will answer these and other questions by discussing:

1. Undesirable effects when not using a balun.
2. Undesirable effects when using a transformer-type balun.
3. A revolutionary balun to solve all the problems.

Let's look, first, at what happens when you do not use a balun. To know why we need a balun, we must first know the paths of current flow in a coax-fed dipole when a balun is not used ... and these are not as obvious as they may seem. We see a flow of two currents in opposite directions on the coax, to provide equal and opposite polarities to the two arms of the dipole. But that's not all — there is a third current flowing on that coax. How can this be?

Well, we are overlooking a common phenomenon called "skin effect," which allows two entirely different currents to flow on the outer conductor of the coax, one on the inner surface of the shield, and another on the outer surface. These two currents flow simultaneously, independent of one another, with no interaction.

Now let's look at these three currents on the coax: Let's call the current flowing on the inner conductor #1 and the current flowing on the inner surface of the outer conductor #2. Currents #1 and #2 are equal and opposite, because they are the total "go and return" currents supplied by the transmitter to the balanced antenna. However, when current #2, on the inner surface of the outer conductor, reaches the antenna (remember, no balun yet), it divides into two paths: one path (current #3) is back down the outside of the outer conductor; the other path is onto the appropriate arm of the balanced antenna. However, the current which flows to that arm of the antenna is something less than current #1, which flows onto the other arm of the antenna. Instead, current #2 (which came up the inner surface of the outer conductor) appears on the antenna as current #2 minus current #3, which divides off to flow down the outer surface of the outer conductor. The magnitude of,this current (#3), which is subtracted from current #2, can be either significant or small, depending on the length of the coax. For example, if the coax is a quarter-wavelength (or an odd multiple), the impedance of that #3 path may be quite high, making current #3 a value which can be disregarded. This would then make the currents in the two antenna arms virtually equal, resulting in the desired radiation pattern. On the other hand, if path #3 is a half-wavelength (or a multiple), the impedance of path #3 will be low, resulting in an appreciable value for current #3, accompanied by reduced current to that arm of the dipole and a distorted radiation pattern. In this case we actually have an antenna with three arms instead of two balanced elements ... and its impedance will most certainly be different ... but don't forget that this situation is extremely "frequency-sensitive" i.e., what looks like a half-wavelength at one frequency will look like a quarter-wavelength at another frequency ... or something in between. An important point here is that, without a balun, the length of the feedline really can tune the antenna ... which is why you hear so much fuss made over the air about trimming the coax to a precise length ... and a certain length of coax can actually

FREQ	W6TC BALUN			COMMERCIAL FERRITE BALUN		
	Z(ohms)	SWR	balance	Z(ohms)	SWR	balance
3.5	48	1.33	2.8%	49	1.21	11.8%
7.0	50	1.19	1.3%	50	1.17	11.6%
14.0	50	1.15	2.5%	55	1.24	7.9%
21.0	51	1.15	4.2%	63	1.37	1.4%
28.0	52	1.18	1.3%	72	1.46	3.9%

provide a resonant antenna system, but before you get excited about solving all your problems by trimming the length of the feedline, remember two points:

1. Trim your coax to acquire a resonant system if you plan operating on or quite near one frequency forever. The typical ham is not going to be content with this restriction.

2. If you're thinking, "I'll just switch in some different lengths of feedline for different frequencies," forget it. The length to which you trim the dipole for resonance is dependent on the length of the feedline, which in turn, governs the reactance of arm #3. So you can't "tune" the antenna system to a new frequency unless you change the length of both feedline and antenna.

One of our opening questions was, "Can we measure antenna impedance accurately at the other end of the line when not using a balun?"

Now we can see why that would be very difficult. The impedance of the "third arm" of the antenna would mask the true impedance of the antenna itself. But the other side of that question is, "Can we measure the antenna accurately when we do use a balun?" The answer is that, with any "conventional" transformer-type balun, impedance-transfer errors obscure the true impedance.

It looks like we're "darned if we do and darned if we don't" ... but there is an answer. First, from a practical point of view, especially for simple dipoles on 40/80/160 Meters, there's usually no need to get "up-tight." The real problems arise with beams, whose more precise directive patterns can be distorted. So, if the transformer-type balun exhibits undesirable characteristics, what else can we do? ... One answer is the choke-type balun:

1. There is no limit to the power that a choke balun will handle, other than the coax of which it is made.

2. There is no impedance-transfer error. The coax, although rolled up, goes straight through to the antenna terminals, so VSWR and impedance plots can be correctly recorded at the other end of the line.

3. The choke action isolates the antenna from the feedline and we have virtually no RF current on the outer surface of the coax shield, thus practically eliminating feedline radiation.

Does this, then, solve all our problems? ... Well, not necessarily, because this type of balun is somewhat frequency-sensitive. It works OK from 20 Meters up but, at the lower frequencies, the amount of coax that must be rolled up to form the choke becomes impractical. This situation can be helped somewhat by wrapping the coax around a ferrite core, but it is not possible to wrap coax tightly enough around the core to avoid coupling losses.

However, Walter Maxwell has come up with a neat solution for all these problems. He discusses it in a comprehensive article entitled "Some Aspects Of The Balun Problem," to be found in *QST*, March, 1983. In this article, he goes into considerable depth on all of the aspects we have discussed here and gives you a balun which you can construct ... or buy, ready-made. Maxwell's balun is a very simple and completely effective choke-type balun which gains its bandwidth by using ferrites, but this time the ferrites do not absorb power or interfere in any way. To accomplish this, Maxwell uses the same kind of ferrite beads we slide over an input wire to keep RF out of a ham rig.

The basic idea here is that a ferrite bead slipped over a piece of wire increases the concentration of the magnetic field around the conductor so dramatically that, in a simplified view, it makes the wire look like a coil, because of the increase in effective inductance. So, if we can find a ferrite bead of the correct size to slip over the outer shield of the coax, we should be able to make the coax look like a coil without rolling it up ... and it turns out that the inductance (and, thereby, the impedance of the outer conductor surface) will increase in almost direct proportion to the number of beads used.

In addition, the beads provide resistance, which is essential, because if the ferrites were responsible for inductance only, the resulting "choke" effect would be frequency-sensitive, and not the same across all the bands ... but the resistance provided by the ferrite beads limits current flow and lowers the "Q" of the effective inductance, resulting in greater bandwidth for the "choke" action. By now, you may be thinking, "Where do we get beads large enough to fit over coax that is large enough to handle the power? ... or, "if there are no beads large enough to slip over RG8, where do we get small enough coax that will still handle full power?"

Well, Walter has the answers. First, you can use either RG303/U, as is, or RG141/U with

the outer fiberglass fabric removed ... and, there are two sizes of beads: (1) one with an inside diameter of 0.197", just the right size to fit snugly over the RG303/U and, (2) one with an inside diameter of 0.190", just right for a perfect fit over RG141/U (after you remove the fiberglass outer sheath). All you have to do is slip enough beads over the coax, right up next to the antenna terminals, in order to form a superb, compact, wide-band balun. The inner conductor and the inner surface of the shield are absolutely unaffected by this arrangement, while the high impedance on the outer surface afforded by the ferrite beads prevents any RF current from flowing back down the outside of the coax. This allows the coax to function properly in supplying a balanced feed to the two balanced arms of the antenna. In addition, ferrites used in this fashion use negligible power and cause virtually no non-linearity.

It would be ideal to make your entire feedline of this small coax (it will easily handle full legal power), but it is quite expensive, so it's more practical just to fabricate a balun. For 1.8 through 30 MHz, you will need a foot of coax and about 50 beads. For the range of 30 through 250 MHz, you need only 25 beads and about five inches of coax. Walter's article covers all the details, including bead specifications and sources.

Both of the coax types feature Teflon insulation and the power-handling capability is 3.5 kW at 50 MHz and 9kW at 10 MHz. With this type of balun, you can measure, at the other end of the coax, almost exactly what is seen at the antenna, with virtually no compromise and, the antenna is fed in balanced fashion, with no degradation of the radiation pattern. Last, the antenna impedance is not influenced by the length of the feedline.

Don't miss Walter Maxwell's article. It's on page 38, *QST*, March, 1983.

Kits containing a small length of coax and the necessary beads are available at:

(1) Amidon, 12033 Otsego Street, N. Hollywood, CA 91607.

(2) RF Kits, Box 441, Greenville, N.H. 03048.

(3) Fair-Rite Products, 1 Commercial Row, Wallkill, NY 12589.

(4) Certified Communications, 4138 S. Ferris, Fremont, Michigan 49412.

And you can buy this balun, all ready to use, in the stores. It's called the W2DU MAXI-BALUN, selling for under $25, and it's produced by Unadilla/Reyco/Inline, 6743 Kinne Street, E. Syracuse, NY, 13057. They have a toll-free number: 1-800-448-1666.

GROUND SYSTEMS FOR VERTICAL ANTENNAS

This electrical field is in the form of a slightly flattened hemisphere. Intersection of the field with ground forms an imaginary circle with a radius of approximately 0.4 wavelength (as applied to a quarter-wave vertical ... the radius of the circle decreases as the height of the radiator decreases).

These displacement currents enter the ground everywhere over the entire surface within the circle and then flow back radially to reach the ground/feedpoint terminal. Although some of these currents penetrate more deeply, most of the RF current flow (at frequencies above 3 MHz) is restricted by "skin effect" to the upper few inches of the ground. A mistake frequently made by hams is to bury the radials too deep. Now, a ground system consisting of only a ground rod or two is only a terminal (the ground/feedpoint terminal of the antenna system). In this case all the return currents must flow through poorly-conducting ground from all points over the entire surface within the circle toward the terminal ... and these current paths through the lossy soil are responsible for appreciable attenuation of the RF power involved. ... The RF loss resistance is often higher than the radiation resistance of the antenna itself! A few radials will provide good conductivity toward the terminal (antenna feedpoint), for the currents which reach those radials ... but only a small amount of the total current entering the 0.4 wavelength circle is picked up by these few radials. All of the remaining currents still flow through the lossy ground, trying to reach either the antenna feedpoint or one of the radials.

If enough equally-spaced radials (extending out to 0.4 wavelength) are present to pick up all the parallel currents, these currents will find highly-conductive paths virtually everywhere within the circle, resulting in negligible loss resistance. Ideally, this would require 90 to 100 radials. This is not to imply that quarter-wave verticals with modest ground radial systems should not be used, nor that fair results cannot be obtained. However, to put it into proper perspective, the difference between a few radials and 100 radials can be more than 3 dB. This is far worse than the loss resulting from, say, 5:1 VSWR on the coax. Since environmental factors vary from site to site, a skimpy ground-plane will give unpredictable results, and VSWR readings are useless.

For example, if the ground return resistance is 15 ohms, this plus the normal 35-ohm resistance of the quarter-wave vertical presents 5 ohms to the feedline. The 1:1 VSWR looks great ... but this is low VSWR for the wrong reason! The meter's happy, but RF power is being expended in the ground.

For practical installations, 40 or 50 radials will do an excellent job for a quarter-wave vertical. Another 40 or 50 would probably not justify the additional cost and effort. Verticals shorter than one-quarter wavelength can be made just as effective as the quarter-wave version by using more radials than recommended for the quarter-wave antenna.

NOTE: Since many of these points are controversial and clouded by myths passed along at night on 75 Meters, I am augmenting this discussion with qualified documentation. I emphasize that these antenna subjects are not expressions of my personal opinions. Rather, they are taken from professional literature (see bibliography below) and paraphrased for simplicity, being very careful not to alter the meaning. In researching these subjects it has become evident that, instead of the many differing opinions held by hams, there is remarkable agreement among the professionals. This is true because the principles involved are based on scientific facts, which are not subject to the divergent opinions expressed in religion or politics!

Bibliography:

Walter Maxwell, "Another Look At Reflections," *QST*, April, 1974.

Brown, Lewis & Epstein, "Ground Systems As A Factor In Antenna Efficiency," *Proceedings of the IRE*, June, 1937 (A classic work on which FCC standards for AM broadcast antennas are based).

Leo, "An Impedance Matching Method," *QST*, Dec., 1968.

Kraus, "Antennas," McGraw-Hill.

Jordan, "Electromagnetic Waves and Radiating Systems," Prentice-Hall.

LIGHTNING PROTECTION

This chapter was inspired by a very interesting letter from Dr. Don Ore, a past MARCO president. He came up with a slightly different but very interesting and completely practical approach.

A main thrust of his letter was in the interest of lightning protection and he made very useful actual measurements of resistances to be expected with various sizes of ground rods. For these experiments, he used a very sophisticated Beckman instrument, one normally employed by commercial firms to determine (for example) that a railroad microwave interconnect system will have an adequate ground system.

The measurement technique involves AC, since conduction through the soil is largely electrolytic. For this experiment, Don installed ground rods to depths of 1.5, 4, 6, 8 and 12 feet in soil which was composed mostly of clay, with some shale. Then, one by one, he measured the resistance between each ground rod and an absolutely perfect ground. The results are very revealing. The 1.5-foot rod measured 840 ohms, the 4-foot rod measured 610 ohms, the 6-foot rod 220 ohms, the 8-foot rod 75 ohms and the 12-foot rod less than 10 ohms.

The foregoing will help you appreciate what Don ended up using for his ground system ... and why. It's obvious that, if one 12-foot rod still shows some resistance (although less than 10 ohms), then several ground rods in parallel would help to further reduce this resistance, important since lightning follows the path of least resistance.

Don practiced what he preached: First, he used 12-foot ground rods ... and let me say here that if you have to use 8-foot ground rods and you want to approximate what Don is doing, you just have to use more of them, in parallel.

And here's Don's setup: He considered his objective in two general categories,

(1) an "earth ground" for lightning protection and

(2) an "RF ground" to provide an effective RF image improving the antenna's performance.

First, his earth ground consisted of two 12-foot ground rods, right next to the north and west sides of his tower base. Each of these was connected to the metal tower with heavy automotive battery strapping. Also, the two rods were connected in parallel with some more of the same strapping.

Next, the RF ground consisted of two more 12-foot ground rods, placed close to the east and south sides of the tower base. These two rods were also connected to each other, but not to the tower. Instead, the shield of the coaxial feedline was bonded to the strapping connecting the east and south ground rods. Also, a number of ground radials were buried a few inches deep and terminated at the east and south ground rods.

One more example of Don's thoroughness was another 12-foot ground just outside the shack.

To quote Don, "If a stroke gets into the shack, you bloody well better have a nice tempting path for the stroke to follow from all those piddly little chassis grounds to a nice low resistance outside the shack ... or, that strike will leave those chassis grounds and go looking for another path, be it a solid-state device, or God's finest creation, man!"

That pretty well describes Don's grounding systems, but he had some additional thoughts worth storing in your notebook:

1. Never run grounds through the concrete tower base. Cement is hygrophilic and will be at higher resistance than the earth, so the lightning could very well split the concrete base on its way to ground. That's why the national electric code specifies that ground rods shall not be closer to the concrete base than 4 inches.

2. Since locations can vary dramatically in terms of ground resistance, the rules of thumb regarding the number of ground rods are:

(a) Put in as many ground rods as you can afford.

(b) Put in as many as you have room for.

(c) Put them as deep as you can drive them.

(d) Tie the whole system together.

3. Use good mechanical ground connections and silver-solder them. This must be done

with a propane torch. Plain solder can possibly melt away when subjected to otherwise undetected strokes. If you can't use silver solder, just use a good mechanical connection only.

4. Automotive battery strapping is good for ground connections, but be sure it is real copper and not a hybrid copper/aluminum substitute.

5. Well service companies usually have large supplies of surplus copper wire for ground radial systems.

6. Don't forget your rotor control cable. It can also bring lightning into the shack. To prevent this, use a complementary pair of male and female eight-pin Cinch-Jones connectors. connect a foot or so of cable from the control head to the female connector. Then, connect the male counterpart to the balance of the cable which leaves the shack and goes up the tower ... and when you disconnect your coax, you can also disconnect your rotor cable.

We're indebted to Don for this excellent material and, if you follow his example, you'll certainly have a first class installation.

By the way, Don's discussion reminded me of a relatively simple method of measuring your ground conductivity: Ground conductivity is measured in units called "mho." This is, of course, "ohm" spelled backward ... appropriate, since conductivity is the reciprocal of resistance. Typical conductivities throughout the country range from near zero to some 30 millimhos per meter, depending on chemical content, moisture, et cetera.

To put this in perspective, salt water has a conductivity of 5,000 millimhos per meter, but fresh water is 10 to 15 millimhos per meter ... and here's a relatively simple way to measure the conductivity with practical accuracy: First, place in the soil 4 metal probes, 5/8" in diameter and 12" deep in the earth. They should be in a straight row, 18" apart. Now, take a 110-volt AC source and connect the grounded side to the probe at one end of the string of four. Next, connect the hot side of the 110-volt AC source to one terminal of a 100-watt, 110-volt light bulb. Connect the other terminal of this light bulb to one end of a 14.6-ohm, 5-watt resistor. Then, connect the other end of this resistor to the ground probe farthest removed from the one to which you connected the ground side of the 110-volt source.

I hope it goes without saying that only now do you turn on the AC source!

Now, take an AC voltmeter and measure the voltage appearing across the 14.6-ohm resistor. Call this V1. Then, measure the voltage between the two center metal probes in the string of four. Call this V2. With these two readings, you can now calculate ground conductivity with this formula:

Conductivity (millimhos/meter) = 21 x VI/V2

A number in the vicinity of 30 will indicate that your grounding requirements won't be quite so rigorous. On the other hand, if the number is one to five, lay in a stock of ground rods and copper radial wire!

FROM BC TO COAX

We seem to take coaxial feedlines for granted, when there is actually a great deal to know about them, if we want to get the most out of them ... and there is much that we don't know about open wire feedlines, since most of us avoid those old-fashioned anachronisms like the plague ... when just a little familiarity with some of their positive attributes might make us think twice. So, I will cover both "BC," or "before coax," and modern coax, showing their comparative characteristics and the advantages and the disadvantages for each type.

The basic idea of coax originated many years ago, but the materials and manufacturing techniques needed to produce coaxial cable that was relatively efficient were not developed before World War II... so the hams back there in "BC" used transmission lines fashioned of wire. Their forerunner of coax was a parallel-wire line using two conductors separated mostly by air. This kind of line was very effective, since there was virtually no loss as long as the wire was heavy enough and the separation between the two conductors was great enough to prevent corona discharge between them. The two wires were held apart at regularly spaced intervals along the line by insulating rods or spacers. For this purpose, all kinds of materials were pressed into service ... polystyrene, porcelin, bakelite, wax-impregnated wood, et cetera. The spacers varied in length from less than 2 to more than 6 inches. The wider spacing was very effective at the lower frequencies, but it was discovered that closer spacing resulted in minimal radiation from the feedline because of more complete cancellation of the fields around the two conductors, especially when feeding a balanced antenna. The two currents in the feedline are equal and opposite and, at lower frequencies, the wider spacing is a small enough fraction of a wavelength for practically complete cancellation, but at the higher frequencies, the wide spacing becomes too great a part of a wavelength and incomplete cancellation is the result. Back in the good old days, open wire line was made of #12, #14 or even #10 wire, and the characteristic impedance was 500 or 600 ohms, typically ... but commercially-available 300- and 450-ohm lines have pretty much superseded the older, larger, home-made types. 450-ohm line is used extensively for TV installations and comes in two versions:

1. The bare wire type, with a pair of #18 wires separated by low-loss polystyrene rods at approximately six-inch intervals. Interestingly, if you use the standard formula for characteristic impedance of this line, you will come out with an indication of somewhat lower impedance, but that is due to a velocity factor slightly lower than if the dielectric were pure air.

2. The second version of "ladderline," as it is called, is made by the same company, Saxton, but it is insulated. It looks like flat 300-ohm TV ribbon, 1 inch wide, and is made of the same #18 solid copperclad wire, but the wire is covered with polyvinyl plastic and performs much better under adverse weather conditions. It has rectangular holes in the center, about 1-1/4 by 5/8 inches, spaced six holes per foot, resulting in a considerable amount of air between the conductors. This line provides good efficiency and very good weatherproofing.

While there is, understandably, a little more loss than with the bare line, the plastic line is a bit more efficient than solid-dielectric twinlead. Additionally, a light nylon cord threaded in and out of the holes in the line can serve as a "messenger cable," removing the stress from the line itself and allowing it to survive ice and/or high winds. Further, where rain and ice may shut you down when using bare wire, this plastic line will keep you in business. The line impedance may change a bit, but not enough to keep your transmatch from handling the situation, and the plastic insulation inhibits corona discharge even more than the bare wire does.

I have used all of the various types of open wire line and I find that you give up very little when using this 450-ohm plastic ladderline, with that small difference being offset by several factors:

1. It is lightweight.
2. It is strong.
3. Loss is still quite low, about 15% of the attenuation loss with RG8, under equal conditions.
4. No twisting and shorting of the conductors, as with the bare wire type.

5. Works well in adverse weather.

6. Velocity factor is relatively high, approximately 90%.

And let's not forget 300-ohm TV twin-lead. A good grade of this line will do essentially the same job performed by 450-ohm line, with very little more loss. Incidentally, dirt collecting on plastic line of any kind can change the characteristic impedance somewhat. To minimize this effect and lengthen the life of the line, give it a thin coat of silicone grease or automobile wax.

Next, for the coax ... There are many types and sizes available, but I list below just the ones used most by amateurs:

For frequencies above the HF bands, the main choices are 1/2", 3/4" and 7/8" "hardline," with foam dielectric and a solid outer shield of copper or aluminum. Losses are much lower than for the coax normally used on HF, but it is hard to bend without kinking, is more expensive and uses very expensive connectors. Understandably, it is used very seldom on HF.

Two additional types of coax are used extensively these days and are worthy of special mention:

1. RG8X, which is not listed in many of the handbooks, is the same overall diameter and presents the same loss as with 59/U, but it has an impedance of 50 ohms and will handle more power with less loss than RG58/U foam. It is normally available in the foam type only. The specifications seem to vary from manufacturer to manufacturer, so be sure to ask your supplier to be specific on the brand he sells. I have heard more than one ham on the air say that RG8X has less loss than RG8. Common sense should tell us that this is not so (and it is not so), but this is a good example of how difficult it is to counteract disinformation, once it gets on the air.

2. RG213/U has become one of the most popular coaxial lines used today, especially for HF applications. It is very similar to RG8, being the same size, 50 ohms and using the solid polyethylene dielectric ... but it is better in four particular ways:

a. The outer braid is more tightly woven, providing 95% shielding.

b. The outer jacket is of the non-contaminating type, giving you a line that will last 20 years. This is an important characteristic, since the popular RG8 foam can become contaminated by chemical action between the outer sheath and the inner dielectric in as little as five years.

c. RG213's solid dielectric will keep the inner conductor centered when stressed by sharp bends and high heat conditions, whereas the inner conductor can move in the foam, even shorting to the shield.

d. The RMS working voltage rating is 5000 volts,, compared to 4000 volts for solid-dielectric RG8 and 1500 volts for RG8 foam.

This gives you a brief description of each of the transmission lines used by most of the hams. Your particular requirements will dictate which is most appropriate. There is often a tendency to be strongly prejudiced in favor of either coax or open wire. The "coax generation" considers mainly the convenience of coax and looks upon the fellow who uses open wire as an old-timer who just hasn't caught up with modern techniques. On the other hand, the "old-timer" who uses open wire feeders may look upon the coax user as one of those young "appliance operators" who knows only how to hook a piece of coax to a resonant antenna. Both, of course, are wrong. There is a most appropriate

TYPE	IMPEDANCE	O.D.	VEL.FACTOR	RMS VOLTS
RG58/U	52	.195	.66	1900
FOAM	50	.195	.80	600
RG8/U	52	.405	.66	4000
FOAM	50	.405	.79	1500
RG59/U	73	.242	.66	2300
FOAM	75	.242	.79	800
RG11/U	75	.405	.66	4000
FOAM	75	.405	.80	1600

application for each of these types of line, after considering several of the factors involved:

1. It makes complete sense to use coax and a balun for any of the 20-, 15- or 10-meter beams, whether triband or monoband. In these cases, the impedance excursions are limited, resulting in minimal loss, even with coax, so why not do it the simplest most practical way?

2. Again, for a dipole used on a single band, coax is the practical answer. It's simpler and cheaper. Incidentally, if the dipole is for 40 or 80 Meters, don't bother with a transformer-type balun at all. In these cases, the radiation pattern is so loosely defined that such a balun won't make that much difference — and, if you run much power, the ferrite core in a transformer-type balun could use a little power.

3. On the other hand, if you want to put up one dipole that will work 80, 40, 30, 20, 15 and 10 Meters, you can forget the coax because a multiband dipole will require "tuned feeders," another term for balanced twin-lead and a transmatch ... or if you want to feed a tower, or some unorthodox antenna whose impedance is far away from 50 ohms, perhaps low-loss balanced line and a transmatch will allow you to stay in your comfortable shack and tune the antenna system, without having to go outside and readjust coils and capacitors each time you want to change frequency. This approach is what I call "The Easy Way" (see chapter 1), but the point is, you must sit down and ask yourself just what it is that you need. If there is no way to get from the antenna to the shack without burying the feedline, the choice is obviously coax. If your rig is at one end of the house and the antenna at the opposite end, we're probably talking coax, although you can run the open-wire feedline around the house under the eaves, so don't overlook that option because, even if the line is four times as long as the coax, loss will be considerably less than with coax.

But every amateur antenna installation is going to be a special case in some respect. If you have questions about yours, please drop me a line, including a simple sketch of your house and lot, and I will be happy to attempt some suggestions.

TOWERS

Every amateur is concerned with the nature of the environment in which to place the antenna, whether it be a vertical, a wire antenna or some sort of beam. If the ham has a couple acres, friendly neighbors, and an understanding spouse, the possibilities are many ... but most amateurs are not blessed with such an ideal setting. First, the typical ham just doesn't have enough real estate. Second, the aesthetic standards of the neighbors and/or the spouse are definite factors. Third, the deed or the lease almost always seems to contain hidden fine-print, restricting additional structures either totally or at least to a height that's never enough to support an effective antenna. Fourth (but by no means least), ordinances passed by the local municipal folks are not generally designed to encourage Amateur Radio operation.

How to cope with these obstacles? ... Well, the typical ham is a resourceful, positive-thinking individual, and he will find a way. He'll be looking for some kind of structure to support his antenna(s) ... and it is our intent here to examine his options. We will investigate these categories:

1. Guyed towers.
2. Free-standing towers.
3. Bracketed towers.
4. Crankup towers.
5. Foldover towers.
6. Roof-mounted towers.
7. Masts.
8. Combinations of two or more of the above.

Let's look first at the guyed towers. In this, as will be the case with other examples to follow, it won't be possible to name every brand but, in most cases, there will be only one or just a few brands used by the majority, and I'll confine the discussion to them.

By far the most popular guyed tower is the Rohn Model 25G. Its cross-section is an equilateral triangle, 12-1/2 inches across each face. The vertical members are 1-1/4 inch 16-gauge galvanized steel tubing. The sections are ten feet long and the cross-bracing is steel rod, welded in a zig-zag pattern, with eight zig-zags per ten-foot section. The ten-foot sections slide together and are bolted with two bolts in each leg, for a total of six bolts joining any two ten-foot sections.

A number of bases are available for this tower. One of the most popular, the SB25G, is the so-called "short base." It is simply a three-foot, four-inch section of 25G tower, which is set in a hole two feet by two feet by three feet deep, and the hole is filled with concrete. Another is a flat steel plate with three stubs welded to it. The bottom section of the tower is slipped over these stubs. This plate can be bolted to three bolts imbedded in the concrete base ... or slipped over a single three-quarter inch steel pin (imbedded in the base), known as a "pier pin." This allows the tower/base to pivot, relieving the tower of strain which might otherwise result from lateral-twisting torque forces.

The flat steel base is also available in a hinged version, allowing the tower to be folded down to the ground. IMPORTANT! ... The hinged base should be used only for relatively short towers and it requires a combination of adequate hoisting equipment and experienced personnel. Other bases include two roof-mounting types, one for flat roofs and another for peaked roofs.

The top of the 25G tower can by finished off in a number of ways. The two most popular top sections are the 25AG4 flat-top eight-foot section and the 25AG3 tapered nine-foot section. The flat-top type provides a good mount for the thrust bearing needed for larger antennas. The majority of the popular beams, though, do not require the thrust bearing and the tapered-top model provides a vertical tube which will accomodate up to a two-inch mast. A rotor shelf, the AS25G, is provided for mounting a rotor several feet down inside the top section.

The 25G towers are normally guyed with 3/16" seven-strand EHS steel guy wire. "EHS" is short for "extra high strength," and the wire is, of course, galvanized. Anchors can be either screw-type (4 feet long with 6"-diameter auger), or anchor rods designed to be imbedded in concrete. In either case, anchors are normally installed at 120 degree intervals around the

tower, at a distance from the base equal to approximately 80 percent of the tower height. Where necessary, anchors may be placed closer to the tower if:

(1) more sets of guys are placed at closer intervals up the tower or

(2) four guys per set are used at each level. This will be explored in more detail in the next chapter.

The 25G will handle the majority of amateur antenna setups ... but the DX-type with stacked monobanders, five-element 40-meter yagis or six-element monster quads will need something more. In these cases, the Rohn 45G will usually suffice. It measures 18 inches across each face and is made of heavier-gauge material (14 gauge).

The next category is the free-standing tower, and the most popular one in this category is the Rohn "BX" type. This tower began its life as the Spaulding tower. It is constructed of lightweight steel stampings and, due to its clever design, is remarkably strong for its weight. The tallest of the BX self-supporting towers is 64 feet. It is made up of eight sections, each eight feet high, each one tapering to a progressively smaller cross-section as the tower gets higher. The bottom (largest) section is more than 28 inches across at the base, and 25 inches across at the top. As the sections go up, the taper continues until the top, or 8th section is only a little over 10 inches at the bottom and a little over eight inches at the top. The tapering is precisely designed to allow all sections of a given tower to nest within one another, making a compact package for shipment. For example, in the extreme case of the 64-foot tower, all the other seven sections nest within the base section, making the whole tower, ready for shipment, just eight feet long. These towers come in three ratings:

(1) The BX, for light duty;

(2) the HBX, for fairly heavy duty, and

(3) the HDBX, for extra heavy duty. The most popular models used by hams are the 40- and 48-foot HDBX types. They are both rated to handle an antenna load of 18 square feet ... which is quite a lot, when you consider that a TA33 presents only six square feet. With the 56- and 64-foot versions getting slimmer at the top, the windload ratings are, respectively, nine and six square feet.

Requiring no guys, the BX tower requires little space and is graceful in appearance. The only catch is that, to provide that 18 square foot rating, several yards of concrete are required in the base.

Next, the 25G, the BX and others can be bracketed to a building. The bracket should be at least 12 feet above ground and, without guys, 40 feet is about as high as you should go with the 25G, and the load should not be much more than a modest three-element beam. On the other hand, if the point where you bracket the tower to the house is strong enough, the BX can support quite a bit more.

The next category is the crankup tower. The most popular models are manufactured by Hy Gain, Tri-ex and Tristao. Most of these extend to heights of as high as 89 feet, cranking down to just over 20 feet. Wind load specifications range from six to thirty square feet and prices from $500-$5,000. With remote-controlled motor-driven winches, prices are even higher.

One popular crankup which is a combination of reasonable price and adequate strength for average use is the Hy Gain HG52SS. This tower is less than $1,000 and can handle nine square feet, needing only about a yard of concrete in the base and, of course, needing no guys.

Next, the foldover tower, made by Rohn: For many who have a modest amount of space, this one is the answer. It comes in heights ranging from 48 to 68 feet, and is based on both the 25G and 45G, depending on load requirements. It is hinged at approximately the middle and the upper half is folded over with the aid of a strong triangular-cross-section boom. This boom extends 18 feet below the hinge, serving as both counterweight and lever, making it easy on both the winch and the fellow who has to crank it.

The amount of real estate needed for a foldover tower is surprisingly small. For the 25G forty-eight footer, the guy anchors are at the corners of a square only 25 feet on a side. For the 58- and 68-footers, the square is still only 35 feet on a side. For the heavier 45G versions, the size of the square is only slightly larger. This tower may be guyed just at the hinge only, if used for modest VHF antennas, etc. However, when in doubt, put guys up at the top, too. By the way, one reason for the compact guy field is that four guys are used at each

level. The base requirements are quite modest, about the same as for other 25G and 45G towers.

I use the 68-foot 25G model foldover tower. I have a four-element tribander at 70 feet (45 pounds/6 square feet); at 80 feet, a rotatable 40-meter dipole (15 pounds/2.5 square feet), and a Hy Gain VS-2 VHF vertical, with the tip at 95 feet. In addition, the load up there includes a Tail Twister (27 pounds) and a heavy-duty steel mast (also 27 pounds). Standing on the ground while working on the antenna is a real luxury.

Next, roof-mounted towers: As I mentioned, 25G tower accessories include bases for either flat or peaked roofs. One or more 10-foot sections can be built up on one of these bases. Obviously, they must be guyed. The guys go to eyebolts at each corner of the roof ... if the roof is strong enough.

Otherwise, the guys can go over the edge of the roof and drop straight down under the eaves to screw-type anchors in the ground.

Also, tripods from three to ten feet high are available. If these are bolted to the roof with bolts that go through to supporting plates inside, such a structure can handle a modest tribander, such as a MiniQuad or a TH3 Junior. The tripod can also support a ground-plane vertical, with the radials slanting down to the roof on all sides. And don't forget the telescoping mast, available in 10-foot increments from 20 to 50 feet high. It collapses to a ten-foot package and can be erected by one man, using light, strong nylon guys. Handle it carefully, though. One slip and a painfully pinched/cut hand is the result. Heavy leather gloves are good protection. The mast makes an excellent support for dipoles and other wire antennas, as well as for omni-directional VHF and UHF antennas ... also VHF/UHF beams and a small rotor. A heavier rotor and beam can be used if the rotator is mounted on the ground, with the bottom of the mast secured in the rotator. The guys are fastened to slip-rings which allow the whole mast to rotate. Another arrangement which gives additional strength to the mast is to bracket it to the house, using a set of guys at the top.

Next, those free-standing towers can be bracketed to the house, needing a lot less concrete in the base, as a result ... and the wind-load rating on some of those self-supporting crankup towers can be raised by bolting them to a building (assuming that the bracketing point is secure). Also, there are some crankups that are more modestly priced because they are designed specifically to be bracketed ... and to satisfy aesthetically sensitive neighbors, there is one model which cranks all the way down to ten feet.

Another option for strengthening crankups is to add a set of guys (perhaps just convenient nylon lines) ... and, the foldover tower can be bracketed to your house, eliminating the guys at the hinge. If the load is light, this arrangement could be used with no guys at all. An added advantage for this approach is that the tower can be folded down over the roof and, if you have a fairly flat roof, it will be convenient to work on the antenna up there.

And, of course, masts can be either house-bracketed or roof-mounted (with nylon guys).

KEEPING YOUR TOWER VERTICAL

In an earlier MARCO Antenna Workshop session, I talked about towers as elements in the overall antenna system, recommending specific tower types to fit with specific environments, depending on such factors as the amount of real estate available, relations with your neighbors ... and your spouse's aesthetic standards. To cope with one or more of these challenges, I suggested a number of choices which included:

Free-standing towers
Bracketed towers
Crankup towers
Foldover towers
Roof-mounted towers
Masts
Combinations of the above

This time I want to go back over those towers with something else in mind ... SAFETY.

It's no joke to wake up some morning after a bad storm, walk outside, and find all or part of your tower in a horizontal position. Even less hilarious is the sight of your antenna in the yard next door. On a more serious note, people can be hurt, even lose their lives because the tower wasn't big enough for the job, wasn't erected properly ... or both.

I want to talk about those factors which can insure you against disaster and contribute to your peace of mind:

1. Tower type/size vs the load on top.
2. Adequate tower bases.
3. Proper guy systems.
4. Safe guy anchors.
5. Proper tower maintenance.

First, the tower itself:

In choosing the right tower, your first and main concern is wind. The wind can do unbelievable things to a tower, and it is of prime importance that you have the greatest respect for that fact. A basic rule-of-thumb is: If there is the slightest doubt, make your tower even stronger than the situation seems to merit. A little extra money spent on your tower may be the cheapest insurance you'll ever buy.

The force the wind exerts against your tower depends on the number of square feet of surface presented to the wind by the tower plus the antennas, masts, rotors, etc. on top. The tower manufacturer gives you a specification which tells you the maximum load, in square feet of antennas, etc., which you can put on top of that tower. This specification means, of course, that you do not have to add the square footage of the tower to the antenna load ... in other words, it means that the tower is strong enough to handle the specified antenna load plus whatever square footage is presented by the tower itself.

In turn, the antenna manufacturer gives you the square footage presented to the wind by his antenna. What this all adds up to is: If the tower manufacturer says his tower will handle a 16-square-foot load and the antenna specification is 12 square feet, you're on safe ground, even after adding the mast and rotor. If, however, antenna, mast and rotor come to just 16 square feet, that might be a little close for comfort ... which brings up an important consideration when choosing the correct tower for maximum safety: ... that factor is, where do you live? The Electronic Industries Association has done quite a bit of research, assembling meteorological data, county by county, throughout the United States, specifying the maximum wind to be encountered in any given location.

I will include a source for completely detailed information at the conclusion of this chapter, so that you can narrow the requirements down to your county but, in general, you will find that you are in one of the following groups:

Zone A ... winds up to 87 mph.
Zone B ... winds up to 100 mph.
Zone C ... winds up to 112 mph.

If the tower has been manufactured to meet standards established by the Electronic Industries Association, the manufacturer will specify, along with the windload the tower will handle, the maximum wind velocity at which such load can be handled. Of course, such specification will also be predicated on following the tower manufacturer's rules for installation, including base and guy system.

It is a good idea to ask questions of the supplier and/or manufacturer. Reputable manufacturers will back their tower if you pick the correct one and install it following their recommended procedure. If you want to learn a lot about tower selection, installation and maintenance, I suggest that you contact either your dealer or Rohn directly and obtain one of their full catalogs. I am not particularly recommending Rohn over other brands, but their catalog is unique, containing a wealth of valuable information applying not only to Rohn towers but to towers in general. My latest information is that Rohn will charge you $5.00 for the book (I think it is worth it), but your friendly dealer will usually give you a copy.

Next, the tower base:

First, it is important to determine whether the base will be used for a guyed tower or a self-supporting tower, and there is a big difference. In the case of the guyed tower, the force of the wind against the tower is translated by the guys from a lateral force into a downward compression, putting that force plus the dead weight of the tower on the base ... and the initial tension of the guys must also be included in arriving at the total which must be supported by the base.

Next, the self-supporting tower is a totally different problem, as far as the base requirement in concerned. Here, with no guys to help, the chunk of concrete on which the tower stands must be a lot bigger, just to keep the wind from uprooting the tower as it would a tree. Added to this is another requirement: Without the help of guys, the wind force against the tower exerts tremendous pressure on the legs of the tower opposite the side from which the wind is coming ... that pressure is downward. Equally important is a strong upward lifting force on the legs nearest the source of the wind. All of this means that the manner in which the tower is anchored into the base is very important ... bringing up a frequent reason for tower disaster: trying to use a tower designed as a guyed tower instead of a real self-supporting tower. Somehow, the reasoning seems to be that, since Rohn 45G sections (for example) are quite strong, it should be OK to put up 40 or 50 feet without guys and put a triband beam up there. Well, the base arrangement was simply not designed for that. Oh, I know, somebody out there is saying, "What is he talking about? That's what I'm doing." My answer is, "I hope you're supporting only a 2-meter antenna, you're in Zone A and the fates are kind!" I have seen people get away with tower setups that would give a good mechanical engineer nightmares, but only for a certain length of time. Always ask for advice from a good tower man or mechanical engineer as to the soundness of your plan. It doesn't cost you anything and it may save you a lot.

Follow the manufacturer's recommendations for your base. Use steel reinforcement bars or "rebar," as it is known, to make the base stronger. Keep the steel all sealed inside the concrete and this will minimize rust problems. This is extremely important: Keep all ground rods outside and at least 4" from the base, bonding those rods directly to the steel tower itself. If a ground rod goes through the concrete base, lightning can split the base, trying to find a path to ground.

Next, guy systems:

Most guy systems consist of three guys at each of several levels, equally spaced around the tower and of equal length, with sets of guys spaced up the tower at intervals no greater than 30 feet ... and even closer if the tower is heavily loaded. For a three-guy system, the guys should be anchored (ideally) at a distance equal to 80% of the tower height. For a light load, such as a small tribander, this distance can be reduced to, say, 65% of the tower height. Where you cannot extend the guys this far, or there is less available space on one side of the tower, you can reduce the distance from the tower to the anchor to as little as 40% of the tower height by using four guys at each level. However, as with three guys, their lengths and the spacing between them must be perfectly symmerical.

Poor choice of guy wire often contributes to tower failure. Somehow the rumor has gotten around that aircraft control cable is just dandy as guy wire. Well, it will rust, is harder to work with and is about 25% weaker than real guy wire. You can get by with it — but do you want to?

The correct guy wire for most ham towers is 3/16" seven-strand EHS (extra high strength) wire. I recommend that you use nothing smaller than this, but it will also handle some towers over 100 feet, depending on zone, windload, etc. Go by the tower manufacturer's

recommendation and you will find yourself using either 3/16" or, for the really big ones, 1/4" EHS wire.

It is important, too, that these guys be tensioned properly. A good rule of thumb is to tension the wire to about 10% of its breaking strength ... and it goes without saying that the tension must be equal on all guys at a given level. The reason for non-stretching steel wire at the proper tension is that the tower must be prevented from twisting when the beam is buffeted by high winds. More towers are destroyed by twisting torque forces than in any other way ... they just twist and collapse. For this reason, when you are using long-boom antennas or stacked monobanders, it is advisable to use special "guy assemblies" on the tower, providing stiff steel arms to improve the leverage the guys can exert in preventing the twist.

Be sure to use good galvanized hardware for your guys. This is no place to save money, and the difference between the cheap kind and the rustproof kind is not worth the gamble. Use three clamps at each junction, and put the "U" of each clamp over the short, or so-called "dead-end" side of the cable. Use "thimbles," those horseshoe-shaped pieces which prevent the cable from kinking when it goes through the eye of a turnbuckle or a hole in a steel plate. Be sure to use the correct turnbuckle for the size of the guy you're using ... and don't scrimp on turnbuckles. Be sure they are rustproof and that the eyes are forged. Finally, when you have tightened up the turnbuckles, put a piece of guy wire through the body and both eyes of the turnbuckle, in a "figure eight," to prevent the turnbuckle from working loose (or in case it breaks). If there is more than one guy terminated at that point, pass the figure eight through all the eyes and turnbuckle bodies.

Connecting the other ends of those guys to the tower is generally accomplished in one of two ways:

(1) when using the guy assemblies previously discussed, the guys are looped through the holes in the ends of the torque arms, using thimbles to prevent kinking;

(2) if there are no guy assemblies and the towers are tubular (such as Rohn), take a single turn around the vertical member, where the cross-members intersect the vertical part ... but be sure the loop also goes around the bends in the cross-members, encompassing both bends and the vertical part, compressing them instead of pulling them apart. After making the single turn around the tower in this fashion, fasten with three clamps as usual.

Next, the anchors:

Conventional anchoring for most amateur towers employs the screw-type anchor. This is a 4-foot by 5/8" steel rod with a forged eye at one end and a 6" diameter auger on the other end. This is simply screwed into the ground at the same angle taken by the guy wire which will be attached to it.

This makes a surprisingly strong anchor for some pretty sizable towers. For example, a 68-foot Rohn 45G foldover tower uses this one. In any case, consult the manufacturer's recommendation. The other anchor normally used when the screw-type is not strong enough is the concrete anchor. This is a 5-foot by 5/8" steel rod, with a forged eye on one end and a crook on the other end, to make it hold when encased in concrete. When two or more guys terminate at the same anchor, equalizing plates are often used to divide the tension equally between the guys.

Through-the-wall anchors and other types are available for those cases where restricted space does not provide room for conventional ground anchors.

Again, the big Rohn catalog describes every conceivable kind of special hardware and includes detailed instructions on how to use such items.

And, last, tower maintenance:

Most of this is just common sense and we really know pretty much what to do ... but time flies and we never seem to get around to it as often as we should. We should check our guys for equal and proper tension. When checking for equal tension, use a long carpenter's level, placing it against the vertical part of the tower to be sure that it is vertical, or "plumb." A perfectly vertical tower is not affected by the unusual stresses which will be present when the tower is off "plumb." All bolts and nuts should be checked to see if they are tight, and replaced if they are rusty. Anything which shows rust but cannot be replaced (such as the tower itself), should be treated. This can be done most effectively with a cold-galvanize

spray. This stuff will form a chemical bond with the good galvanizing around the rust spot and prevent further rust formation, making the spot virtually as good as new. There are several brands of this material. The one I have used with gratifying results is the LPS brand.

And, before concluding, I would like to add a few notes:

1. Be very careful about hinging towers at the base and walking them up. This may appear to be the easiest way to erect 40 or 50 feet of tower but, more often than not, it is the hardest and most dangerous. If you have plenty of people present, at least one of whom understands mechanical stresses, proceed carefully. If not, you may be surprised how much easier it is for two people to put that tower up, one on the tower with a safety-belt and a "gin-pole" ... and the other on the ground to handle the pulley-rope and pick up the tools you drop!

2. A couple comments about that mast you put in the top of the tower to support your beam:

(a) Be aware that, if the height of the mast above the tower is, say, 10 feet, and the wind is blowing only 60 miles an hour against 8 square feet of antenna, there are some horrendous forces trying convert that mast to macaroni!

(b)You'll be safer with a good steel mast. A good aluminum-alloy mast may be lighter and just as strong ... right up to the instant that it crystalizes, something that doesn't happen to a tough steel mast.

3. High-quality close-woven nylon can do a good job when used for the right job ... for instance, for supporting masts or the ends of wire dipoles ... but, for towers, it is a different story. Remember, twisting destroys towers, so, very simply, nylon guys will stretch enough to let 'em twist and steel won't. Incidentally, when guying masts, use only close-woven nylon. The older it gets, the tougher it gets, but the hot sun will eventually disintegrate dacron and other synthetics.

4. One more comment on anchors and bases: all that I have said thus far has been predicated on normal soil. When the soil is swampy or sandy, consult an experienced tower man or a civil engineer.

5. A couple notes on climbing:

(a) Spend the money for a good, approved safety-belt. It's cheap insurance. A friend and former colleague lost his life using a home-made safety belt.

(b) When climbing a tower, you come to the moment of truth every time you have to unhook the belt to move up around a set of guys. It may be a little more trouble but it is not a bad idea to provide your belt with two lanyards. Then, you can leave one fastened around the tower below the guys until you have fastened the other one above the guys ... after which you can unfasten the lower one and move up with complete safety. If you are squeamish about climbing towers anyway, this system can provide some reassurance.

An excellent source for expanded detail on this subject:

"Structural Standards for Steel Antenna Towers and Antenna Supporting Structures," EIA Standard RS-222-C, March, 1976, from EIA, 2001 Eye Street, NW, Washington, D.C. 20006, $7.40.

THE BASIC ANTENNAS

THE DIPOLE

One of the most-used words in the world of antennas is "dipole." This word, in its basic context, denotes a device which has two poles, or terminals, into which currents flow. In this case, the "device" is an antenna, and the currents which flow are RF currents, producing a radiated radio frequency field.

Actually, a dipole may be any reasonable length ... but the word "dipole" does create some confusion because it is so often used in conjunction with "half-wave" that we tend to think of it as always being a half-wave antenna ... not so, though a dipole can be a "short dipole," a "full-wave dipole," or any other length.

This discussion will concentrate on dipoles for just one frequency (7.235 MHz), for simplification, but be mindful that all parameters can be applied to other frequencies/bands by making them proportional to the required frequency. First, we'll cover those factors essential for understanding, building and operating a conventional (so-called) "thin wire dipole." Then we will look at some variations, both in dipole types and in feed systems.

Of prime importance in discussing any antenna is knowing the difference between "radiation resistance" and "feedpoint impedance." These two terms have different meanings, although they are often confused with each other ... and these differences should be clarified from the start:

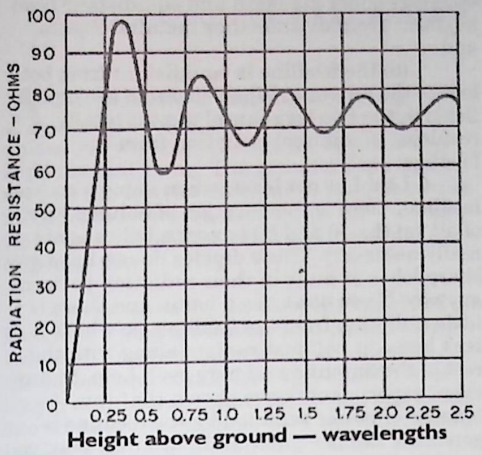
1. Radiation resistance is that resistance measured at a point on the antenna where there is also a current maximum. If we feed a conventional half-wave dipole in normal fashion, in the center, this is the point of maximum current also and, in this case, radiation resistance is approximately the same value as feedpoint impedance.

2. Feedpoint impedance, however, can be vastly different from radiation resistance, if the antenna is fed at some point other than the maximum current point. For example, if the half-wave dipole is fed at one end, the feedpoint impedance will be very high (and the current at that point will be very low) ... but the radiation resistance of that dipole still remains the same low value measured at the point of maximum current (the center).

Now, let's look at the "radiation resistance" for the half-wave dipole. Of course, since we will stick with center-feed, both radiation resistance and feedpoint impedance will be virtually interchangeable throughout this discussion. Radiation resistance for the half-wave dipole is typically in the 70-ohm ballpark. However, depending on its environment, actual radiation resistance of a half-wave dipole may vary from 10 to over 100 ohms. These differences are influenced mostly by the antenna's height above ground, and are well illustrated (figure 29, page 2-20) in the latest "ARRL Antenna Book" (also figure 2-44, page 50 of the previous edition [brown cover]). From this graph, I have extracted some representative numbers which apply specifically to a half-wave dipole for 7.235 MHz. This graph displays variations in radiation resistance versus antenna height above a perfectly conducting ground.

Beware, though ... the chart shows, for example, 10 ohms at 7 feet above ground ... but that's true only if the ground system is as perfect as solid copper. In real life, the closer you get to ordinary average ground, the more power is coupled into the ground and lost ... and this "loss resistance" appears in series with the antenna resistance, as far as the feedline is concerned ... making the total get higher and higher as we get closer to ground. If the antenna is quite close to ground the total resistance of the antenna could be several hundred ohms ... so don't get carried away with the chart when the antenna is close to average ground. This also helps to explain why you get unexpected results when the antenna is not too high up ... so let's just look at the chart, starting with an antenna at least a quarter-wavelength above ground and go on up.

Notice that, as we reach the first quarter-wavelength above ground, the radiation resistance arrives in the 73-ohm ballpark (73 ohms is the ideal optimum value in free space). From here on up, this value will repeat, at approximately every quarter-wave of additional height ... and, in between, something also happens every 1/8 wavelength, except that it alternates being higher or lower than 73 ohms. For instance, at 1/8 wavelength above the first quar-



ter-wavelength, where we are 50 feet up, the radiation resistance goes up to 95 ohms. Then, at two quarter-wavelengths, or a half-wavelength up (68 feet) we are back to about 73 ohms ... and another 1/8 wavelength up, at about 80 feet, we are down under 73 ohms, to about 58 ohms. At three quarter-wavelengths (102 feet) it's around 73 ohms again; another 1/8 wavelength to 110 feet shoots it back up to 83 ohms and, at a full wavelength (136 feet), we are back down to 73 ohms. As we go higher and higher and this cycle repeats, we continue to come back to 73 ohms, and the excursions above and below grow smaller with each cycle until, several wavelengths up, we reach the practical equivalent of "free space" and the cycle flattens out to a steady 73 ohms.

From this, you can see that, to be sure of a predictable 73-ohm impedance for our dipole, we would have to use some pretty tall structures ... beyond the height most of us would be able to provide and remember, we would have to be double these heights for 80 Meters. This means that we will be putting up dipoles relatively close to the ground (in terms of a wavelength) and that we must be aware of the practical limitations indicated by the chart in the Handbook. In the average case, one of two things will happen:

1. The typical dipole at modest height should not be far from 50 ohms, certainly close enough for the pi net in your rig to match it to the amplifier ... but remember, the feedline impedance which your rig sees will present both resistance and reactance, which is why you need the rig's pi net to effect a conjugate match between the feedline and the rig ... and, if it is a solid-state rig, a transmatch may be necessary to accomplish what the pi net does in the tube-type rig.

2. More likely, you'll have some SWR, but not much worse than 1.5:1 at the resonant frequency of the antenna. If you have a tube type amplifier, you can live with this. Otherwise, a transmatch will let your rig see 50 ohms anywhere on the 40-meter band — which brings us to 300- or 450-ohm balanced twinlead ... using this and a transmatch, you can also tune 20, 15 and 10 Meters, showing your rig a perfect load on any frequency and operating with high efficiency.

Another dipole which covers all the bands pretty well, without a transmatch and using coax feedline, is the "G5RV." It is a dipole, 51 feet long on each side of the center feedpoint (total, 102 feet). At the center feedpoint, you connect 29 feet of 300-ohm TV twinlead. Then you connect any desired length of 50-ohm coax to this twin lead, put a PL259 connector on the other end and you are in business on all bands, 80 through 10 meters. Since you don't have a transmatch, don't expect the antenna to be ideally flat everywhere, but you do have the convenience of coax, and the simplest kind of transmatch will let this antenna present a 50-ohm resistive load to the rig on every frequency.

Another dipole for 7.235 MHz is the folded dipole. This antenna features a much higher feedpoint impedance, on the order of 300 ohms. It can be used quite nicely with a 300-ohm TV twinlead feedline and a transmatch with balanced input terminals. One thing to remember about this antenna, though, is that it does not like to work on an even harmonic of the fundamental frequency. For example, a 40-meter version does not work well on 20 Meters. However, it will work well on odd harmonic bands and will, therefore, do quite well on the 15-meter band.

And here are a few footnotes, applicable in general to any of these dipoles:

1. The inverted-V configuration can be used with any of these dipoles, and is really more practical and more popular than the flat, horizontal dipole. It is also easier to erect, requiring only a single center support. The

ends can then be tied off to convenient trees, fences, buildings, etc. Take care to balance the two ends, regarding proximity to ground or metal objects. It is also very important that the angle of the V at the apex be no smaller than 90 degrees, with 120 degrees being an ideal angle. Anything less than 90 degrees will result in too much coupling between the two halves of the dipole, causing partial cancellation of the signal and weird tuning conditions. It should also be mentioned that drooping the antenna into a V results in a somewhat shorter antenna and a lower feedpoint impedance. If you are going to use a transmatch, these differences are not important.

2. Feedline lengths for balanced, tuned feedlines are subject to some possible adjustment, depending on antenna height, and an antenna's specific environment. If you are using a versatile "T" type transmatch, and cannot get a perfect match on all bands from the fundamental frequency up, the feedline length needs to be changed. The length is not at all critical on the fundamental frequency but, if it is not right, the higher the frequency, the more difficult it is to get down to a 1:1 match. If you encounter this problem, just experimentally lengthen or shorten the feed line a few feet at a time until, suddenly, everything falls into place on every band and when you tune for a 50-ohm load on any frequency, it will be easy.

3. More about tuned feeders: Currents in the two wires should be equal and opposite in direction. To achieve this, be sure that

(a) the antenna itself is balanced, i.e., both legs equal in length and equidistant from adjacent grounds and other metallic objects, and

(b) the feedline is equidistant from both legs of the antenna. When currents are equal, fields in the two legs cancel almost totally, resulting in minimal radiation from the feedline.

4. Last but not least, when using a coaxial feedline, there is the question of baluns: First of all, on the 40 and 80 bands, a balun is not really necessary. These dipoles do not have any sharp lobes or nulls in their radiation patterns anyway. If you don't use a balun and there is a little radiation from the feedline, so what? It isn't lost ... it will just radiate along with the rest of the antenna and may even help. In any event experiments have shown that the amount of power radiated by the feedline is generally inconsequential. If, after all that, you would still feel better with a balun, at least use either an air-core balun, such as the Bencher, or, better yet, ... Walter Maxwell's "W2DU MAXI BALUN" ... the best of all.

There are other kinds of dipoles: trap, fan, coaxial and cage dipoles, for example. They all work. Each has advantages and disadvantages but, as Walter Maxwell says, "regardless of the kind of dipole you are using, if it is located in the same place, tuned to the same frequency, has the same ohmic resistance and is fed the same power, it will radiate in pretty much the same way" ... So pick the one which fits your needs in other ways and you'll do OK.

THE ZEPP ANTENNA

Actually, there is probably not a real, original "Zepp" antenna in use today, unless you want to consider an upside-down Zepp the real thing. The genuine Zepp was used on the heavier-than-air balloon known as a Zeppelin. However, the "balun," or the "balloon," as it is so often mispronounced, did not originate there ... HI!

The antenna for the Zeppelin consisted of, basically, a quarter-wavelength parallel-wire twinlead, dropped down below the airship. At the bottom end of this feedline, a half-wavelength of wire was connected to just one of the two wires in the feedline, with the other side of the feedline unconnected to anything. Also, the bottom end of the feedline was stabilized with an aerodynamically-designed weight, heavy enough to hold the feedline mostly vertical, with the wire antenna itself trailing behind the fairly slow-moving aircraft in a horizontal position.

This, then, was the "Zepp" antenna. Its first application in the ham world was brought down to the ground and turned upside-down. Of course, this was simply an end-fed half-wave antenna, but the parallel-wire feeders were known as "Zepp feeders" so it was not long before the antenna became commonly referred to as an "end-fed Zepp."It followed naturally for other types of antennas to be associated with the name if they used Zepp feeders. The center-fed Zepp, off-center-fed Zepp and Zepp-fed Windom antenna were examples. As a matter of fact, you can find a very different application of the term "Zepp" in the new English book, "HF Antennas for All Locations," by L.A. Moxon, G6XN. This is, by the way, a Radio Society of Great Britain publication and, typically, is very good. In this book, on page 192, you will find specialized Zepp feeds for directional antennas. In the index of this book you will also find four other Zepp references, none resembling the original Zepp.

But let's go back to that first upside-down, end-fed Zepp. The earliest reference (in ham literature) that I can find is in the 10th edition of what is now the 22nd edition of Bill Orr's "Radio Handbook." The 10th edition, though, came out in 1946 and, at that time, it was edited by Woodrow Smith and published by a group known as "Editors and Engineers." This handsome hard-bound volume was available, all 704 pages of it, for the princely sum of $2.25 ... but wait! ... already inflation was beginning to rear its ugly head. There is a sticker over the original price raising it to $2.50, or $2.75 delivered anywhere in the U.S., which should ring a bell about today's postal rates ... and, of course, today's 22nd edition of the "Radio Handbook" sells for $39.95. It is 30% larger but, if the price of the old book were increased by 30%, it still would be only $3.25.

Let's look, then, at the land-based end-fed Zepp, as described in the 10th edition of the "Radio Handbook": It says, "the Zepp antenna system is easy to tune up and can be used on several bands by merely retuning the feeders ... where space is limited and where operation on more than one band is desired, the Zepp has some decided advantages." As I said before, the authentic Zepp feeder is quarter-wavelength. This is what you get when you fold one half of a full-wave antenna back on itself to form the twin-lead feedline.

Picture, then, a feedline oriented vertically, with a half-wavelength of horizontal wire connected to one side of the top end of the feedline. The other side of the top end of the feedline is not connected to anything. At the bottom of the feedline, the two sides are connected to a coil, which is used to couple the feedline to the transmitter, and a variable capacitor is placed on one side of the feedline to tune out the inductive reactance introduced by the coil. The net objective of this arrangement is to make the total electrical length of the feedline an exact half-wave from the point where the top feeds the antenna, down through the coil and back up to the other side of the top of the feedline (the side that is not connected to anything). This half-wave should be equal, in electrical length, to the other half, which is the antenna itself.

Now, I want to emphasize that, up to this point, I have been giving you historical information on the original Zepp, to lay some groundwork for more modern and practical applications of the basic idea.

First, although in the minority, there are still some end-fed Zepps, somewhat as I have described. This version is used mainly for convenience, where the wire must be fed at the end instead of at the middle. I emphasize, though, that the center-fed version is infinitely more desirable whenever possible. Most of the end-fed Zepp problems stem from the fact that the end-fed half-wave flat-top is fed at a very high-voltage point. This makes it very difficult to balance the currents on the feedline, because voltages on the two sides of the top end of the feedline cannot be equal. Obviously, the open side of the top of the feedline will be at a higher potential than the side connected to the flat-top antenna. Now, a parallel feedline in which the currents are equal will not radiate because the currents flow in opposite directions and their fields cancel almost completely. When equal feedline currents are not possible, as in the case of the end-fed Zepp, RFI in the shack is more the rule than the exception, but it can be minimized with careful tuning and a good ground system, plus sticking to one band and pretty close to one frequency.

However, there are many advantages to be realized when "Zepp" feeders are used on some kind of balanced antenna. Getting into balanced antennas, let's look again in that 1946 "Radio Handbook," which says, "A current-fed doublet with twin feeders, sometimes erroneously called a center-fed Zepp, is an inherently balanced system (if the two legs of the radiator are exactly equal electrically), and there will be no radiation from the feeders, at any frequency the system is operated on. The system can be successfully operated on almost any frequency, if the system as a whole can be resonated to that frequency. Incidentally, its interesting to browse through this 1946 Handbook and find no coax, or connectors for coax, as we know them today. Most feedlines were either single or double open-wire lines. A couple of very primitive rotary beams are described, using parallel feedlines.

The word Yagi is never mentioned and there is brief mention of coax which apparently had considerable loss, since only the shortest runs were recommended, mainly used to go around the the rotator, allowing the beam to turn, but then spliced into balanced open-wire line the rest of the way. So much for history ... now, let's examine the modern "Zepp":

The standard modern center-fed Zepp, in its basic configuration, is a half-wavelength center-fed dipole. It can be either a flat-top or an inverted vee. The feedline can be 300-, 450- or 600-ohm balanced line and is basically a quarter-wavelength (or an odd multiple) at the lowest operating frequency ... although any length that will tune all the frequencies you need will provide good performance and efficiency.

For maximum flexibility and ease of tuning, the transmatch should use the "T" type of circuit. There are several variations of this basic design. One is Lew McCoy's "Ultimate Transmatch," with one section of a two-gang variable capacitor appearing from the transmitter input to ground. This is supposed to provide appreciable harmonic attenuation and, depending on the nature of the antenna it encounters, it may provide some harmonic attenuation. When facing other load conditions, though, harmonic attenuation may be minimal. However, there is too much fuss made over this point. We should stop and remember that we are looking for an antenna-matching device, not a low-pass filter. Therefore, any harmonic attenuation at all is a bonus ... and modern rigs with pi-network output circuitry and good low-pass filters are already clean enough, if operated properly. I have built both the plain "T" and the Ultimate Transmatch ... and either one will do a good job. I have also built Doug De Maw's SPC version. This is another variation of the "T" match, in which the two-gang variable capacitor is used on the antenna side of the transmatch. Here, the second half of this capacitor will be in parallel with the shunt coil. This is, perhaps, a bit more effective but, for one thing, both the "Ultimate" and the "SPC" are more difficult to tune on 160 Meters and often have a tendency (especially on 80 and 160 Meters) to arc across the tuning capacitors, even with moderate power applied. The simple "T" tunes more easily and does not present this problem. Features of real importance in a transmatch are:

1. It should have nice wide-spaced variable capacitors, to minimize the possibility of arcing.

2. It needs a variable inductor which changes inductance in increments no greater than every other turn. This can be accomplished with either an 18-tap rotary switch or a rotary coil with roller contact.

3. It needs high-quality vernier controls, to facilitate tuning and logging, and to provide reliable resettability.

Now, we have a half-wave dipole, balanced feedline and a good matching device, so we have a complete antenna system. Let's make this dipole 125 feet long and see what a wonderfully versatile and efficient antenna system we have:

1. On the 80-meter band, we have a half-wave dipole, using very low-loss feedline, which will show your radio 50 ohms, resistive, at any frequency across the considerable spread of this entire band ... and, most importantly, it will do it at efficiencies of better than 95%.

2. On the 40-meter band, it's two half-waves in phase, with 1.9 dB theoretical gain and the rig sees 50 ohms across the band at high efficiencies. Beamwidth on 80 was about 90 degrees; on 40 it is 60 degrees, broadside to the dipole (if the antenna is a flat-top at least a half-wave above ground).

3. A most attractive feature of this 125-foot dipole is that, by happy coincidence, on the new 30-meter band it becomes what is known as the "Extended Double Zepp." By definition, each half of an extended double Zepp should be 5/8 (or .625) wavelength. Next, a wavelength in the middle of the 30-meter band, measured at the center frequency (10.125 MHz), is about 97 feet ... so 0.625 times 97 is about 60.6 feet for each half of the dipole, or a total length of just over 121 feet, but most texts, based on actual test results, recommend a little more, with the multiplier being 0.64 wave length for each half of the dipole. This comes out just under 125 feet, so our 80-meter dipole is just right. This allows 49-foot half-wave sections at each end of the dipole (for 30 Meters), and the 27-foot piece left in the middle does several things:

a. It separates the two outer half-wave sections and allows them to radiate in phase, but independent of the undesired mutual coupling effects found with two collinear half-wave elements.

b. The center 27-foot section is out of phase with the two outer half-wave sections.

c. The center section is a relatively low-current portion, radiating very little and allowing the two outer half-wave sections to combine for a broadside gain of just under 3 dB, with some very minor lobes at acute angles to the axis of the antenna.

4. This antenna will also tune with equal ease and efficiency on 20, 15 and 10 Meters. The only catch here is that the pattern will be a cloverleaf on 20, with these lobes moving around to fire more off the ends of the antenna as you move on up through 15 and 10. However, you can have a lot of fun on those bands with this antenna, and I have worked lots of DX up there with the center-fed Zepp.

THE G5RV ANTENNA

G5RV is the call for R.L. Varney, Sussex, England. He is best known for having "invented" the G5RV antenna, although the British say that the Collins multiband dipole of the '30s "appeared at least similar," which is a rather singular remark, the Collins antenna having been used quite a few years prior to the emergence of the G5RV ... more about this later.

The G5RV is a dipole, fed mostly with coax, but with a matching section of twinlead transmission line between the coax and the feedpoint of the antenna. This dipole can be made of any standard copper antenna wire, #18 to #14. The overall length is 102 feet (51 feet on each side of the center feedpoint). The feedpoint is provided by placing an insulator between the two halves of the antenna, allowing a balanced feedline to be connected to the antenna at this point. The feedline may be 450-ohm wire line, about 34 feet long, or 300-ohm TV twinlead, about 29 feet long. The other end of this twinlead section is spliced to 50-ohm coax, which may be just about any length, although it would be well to make it over 65 feet long. This would make it over a quarter-wavelength at the lowest frequency normally used, isolating the outer conductor of the coax from the antenna matching section effectively, thus minimizing radiation by the feedline. (Let me emphasize here that such radiation is not the kind that causes TVI ... it is merely radiation of the fundamental transmitted frequency ... so, the only undesirable effect would be less power radiated by the antenna proper ... and, sometimes, the power radiated by the feedline may even enhance the radiation pattern, so it is not all that much to worry about!)

Next, put a PL259 connector on the transmitter end of the coax, and you're in business.

In experimenting with this antenna, I used a 40-foot telescopic mast for the center support. It's a good idea to place a pulley and use a nylon line to raise and lower the antenna for experimenting and service.

Incidentally, I used the antenna as an inverted V, but it can, of course, be used in the flat-top configuration, with not a great deal of difference in performance or practical results. In the average case, though, the inverted V is used, since only one high point is needed, with the ends being tied off on convenient trees, houses, etc. The usual precaution applies regarding the minimum angle at the apex. The included angle between the two antenna arms should be at least 90 degrees.

It is also desirable to keep the open wire matching section at least a foot away from metal poles, towers, etc. It may run more closely if it runs <u>across</u> something metallic, but it should not run <u>parallel</u> to metal for any considerable distance. In view of the fact that this antenna functions without benefit of a transmatch, it works quite well on the five basic HF bands (80 through 10 Meters). Here's how it works:

1. <u>75/80 Meters</u>: The electrical center of the antenna (for this band) is <u>NOT</u> 15 feet down the balanced line matching section, allowing the antenna to function as a half-wave dipole. This oversimplified explanation appears in some otherwise reliable books, but the G5RV is simply a dipole matched by the twinlead section.

2. <u>40 Meters</u>: Functions as two half-waves in phase (again, using twin lead section for approximate matching.

3. <u>20 Meters</u>: Now the antenna functions as one which extends three half-wavelengths. It is claimed that, if this antenna is placed either a half-wavelength or a full-wavelength above ground (for 14 MHz) and then raised or lowered slightly, the SWR can be optimized. However, the overall difference is negligible. What is more important is the old axiom, "higher is better."

4. <u>15 Meters</u>: On 21 MHz, the antenna is two wavelengths in phase, capable of excellent performance. Incidentally, as these higher frequencies are reached, efficiency is improved by using twinlead for the entire feedline, instead of just for the matching section (of course, this requires a transmatch and the antenna is no longer a G5RV!

5. <u>10 Meters</u>: On this band, we have two 1.5-wavelength antennas in phase. Here again, twinlead all the way would definitely improve performance ... and British sources agree (see references at the end of this talk). As I say, this would no longer be, strictly speaking, a "G5RV." Rather, it would be the old Collins multiband

antenna. This means that the 102-foot length would no longer be critical (in fact, "tuned feeders" will handle anything from, say, 100 to 150 feet when used for 80-10 Meters).

So as you can now see, the G5RV is really an adaptation of the Collins multiband idea, allowing it to be used without a transmatch ... but since we seldom get something for nothing, let's look at a few comparisons:

1. While the G5RV "works" on all five bands, you will encounter some SWR readings of 3:1 or higher on some frequencies. This is bearable for tube-type rigs but not for solid-state types.

2. Even if the tube-type will load up with a 3:1 SWR, one factor is generally overlooked: For the pi network in the rig to reduce harmonic output to a minimum, it must be properly matched at both ends ... which would not be true in this case.

3. The transmitter will transfer maximum power to the antenna system when it sees a 50-ohm load. Otherwise an impedance mismatch will result in something less than maximum power being transferred out of the amplifier ... meaning more power to be consumed within the amplifier, producing more than normal heat. Contrary to one of the popular "old wives' tales," it is an impedance mismatch that causes the heating of the amplifier ... not "reflected power coming back down the line and running around the amplifier!"

In light of these facts, I ended up with the "center-fed Zepp" (just another name for Collins' multiband antenna). The G5RV is a very good antenna if you don't have a transmatch. It's simple and costs very little — but if you have a transmatch, you don't need the G5RV. There's nothing magic about it ...

THE WINDOM ANTENNA

One of the simplest and most economical antennas for multiband amateur use is the horizontal wire, fed off-center with a wire and known as "the Windom Antenna."

Oddly enough, the real development work on this antenna was the result of a thesis by John Byrne, then 8DKZ, and E. F. Brooke, 8DEM, under the guidance of W. L. Everett, well known for the text, "Communication Engineering," a standard college reference in the 30s and 40s (Everett retired as Dean of Engineering at the University of Illinois, with the title "Dean Emeritus").

In July, 1926, the technical editor of *QST*, R. S. Kruse, published a roundup of feed methods which included a discussion of the off-center feed method by Loren Windom, 8GZ, a fellow student with John Byrne. Windom never pursued electronics professionally and became a lawyer, practicing in Ohio. However, he remained an active ham and his call, W8GZ, can still be found in the 1984 call book.

John Byrne, who with his thesis partners, E. F. Brooke and A.B. Crawford, did much of the actual development work on the Windom, later became an outstanding research engineer and educator.

The original antenna, as described by Windom in the *QST* article for September, 1929, took advantage of the fact that, when an antenna is resonant, the impedance anywhere along its length is a pure resistance which, in practice, can vary from under 50 ohms to over 5,000 ohms, depending where you tap it. So, there's always a point somewhere on the antenna which will match the impedance of the feedline.

The original Windom antenna was essentially a one-band antenna and sometimes pretty critical to adjust. In those "pre-SWR" days this was accomplished by running a neon bulb along the feedline to see if there were any pronounced standing waves.

Soon after this, G2BI showed that by cutting the feeder carefully to make the whole system resonant, it was possible to use a Windom effectively on, say, 7 and 14 MHz. Then, Jim MacIntosh, VSlAA (now GM31AA), introduced a new idea ... quite an important one ... called the "one-third tap." During the course of his experiments with a 264-foot Windom, it occurred to MacIntosh that there must be an arithmetic relationship between these mythical tapping points on the different bands, and so it proved, resulting in the VS1AA version, which is still going strong. It consists, typically, of a 138-foot horizontal wire, tapped one-third of the way from one end, and it's useful for 3.5, 7, 14 and 28 MHz.

But the Windom is used less today because: (1) the single-wire feedline radiates, resulting in radiation losses; (2) it suffers from ground losses in a manner similar to those experienced by a vertical with no radials; (3) it works well only on even harmonic frequencies (not, for example, on 15 Meters if the antenna's fundamental frequency is 80 Meters). However, there are later versions of the Windom which remedy some or all of these problems:

1. VS1AA's solution to the 21 MHz problem was to use a very long wire and tap it 26.5 feet from one end. This extra length provides heavier damping of the standing wave and adjustment is less critical. In practice, this overcomes the difficulty presented by harmonic resonances that are not even multiples of the fundamental frequency. This scheme works quite well from 7 MHz up (including 21 MHz), if the the wire is at least two wavelengths long at 7 MHz.

2. Another version is known as the "Double Windom." This, again, eliminates feedline radiation and attendant TVI/loss problems otherwise experienced with the single-wire feedline. This antenna is actually two Windoms separated by a center insulator. Visualize a dipole (with an insulator in the center), 66 feet long. Now, tap the antenna 11 feet either side of the insulator with two 22-foot wires, and bring those two wires down to connect with a balanced open wire feedline, so that what you have looks like a large "delta match" arrangement. Used with a transmatch, this antenna performs very well on all frequencies from 7 to 30 MHz, with none of the above problems.

Good references on the Windom include:

"Radio Communication Handbook," Volume 2, 5th edition, published by Radio Society of Great Britain, pp. 12.58, 12.59.

"Amateur Radio Techniques," by Pat Hawker (OVA), 5th edition, published by Radio Society of Great Britain, pp. 221, 222, 268.

A very comprehensive article in *Ham Radio*, May, 1978, by John Nagle (K4KJ), presenting a fascinating historical background for the Windom, plus technical coverage.

THE COAXIAL DIPOLE MYTH

Now, before your blood pressure rises and you turn me off, let me preface this discussion by saying that the coaxial dipole (misnamed the "double bazooka") doesn't perform any differently than any other dipole, for all practical purposes. It just doesn't perform any better, and there are some strange and wonderful capabilities attributed to the coaxial dipole which are purely fictional, put forth by a number of ham magazine articles based more on imagination than on fundamentals of electronics and physics.

As Walter Maxwell says, "Misinformation, like a rumor, is difficult to stop, especially if it is in print. So, before you hurry out to buy the coax and spend time and effort building the coaxial dipole, I believe it is in your best interest to learn that, although this antenna will perform like a dipole, it will not live up to the optimistic claims made for it." These claims appear in a widely circulated mimeographed publication written by WA9PIV. However, in a *QST* article, July, 1968, Charles Wysall, W8TV, reveals that the coaxial dipole was originally developed at Massachusetts Institute of Technology for radar, and it was very successful in this service, since it used special gas-insulated and air-insulated coax with a velocity factor near unity, and surge impedance could be selected to meet the specific requirement (see "Communication Engineering," Everitt & Anner, 3rd Edition, McGraw-Hill, pages 492-8). But here's one of the major problems with the amateur version of this antenna: When you use standard 50-ohm coax and a thin-wire radiator, it just doesn't work like the M.I.T. version, which had a fat tubular radiator with a length/diameter ratio of 120:1 and a feedline impedance of 100 ohms. We will examine each of the mythical claims made by WA9PIV for the ham-style "double bazooka," which are as follows:

1. Broadband performance.
2. 1.5 dBd gain.
3. Has built-in balun.
4. Provides harmonic attenuation.
5. Lower noise.
6. Has directivity greater than a dipole.

The antenna consists of a section of RG58 coax, internally an electrical half-wave long, but 34% shorter externally, due to the 0.66 velocity factor. The outer shield is parted in the center. The inner conductor, complete with its dielectric, is left intact and runs right through the center feedpoint. The two inner ends of the shield, where it was parted, are used as the feedpoint for the antenna, which means that the outer shield of the coax becomes a portion of a center-fed dipole. Then, the inside conductors (which do not radiate) are shorted to the outer shields at the outer ends to form quarter-wave shorted stubs, leaving the high-impedance open ends at the center, facing the feedpoint. At frequencies off resonance, the stub reactances appearing at the feedpoint change in a direction opposite to the direction in which the antenna reactance is changing, with the intention of increasing the antenna's bandwidth. At this point, the author (Wysall) says, "The antenna can be adapted for amateur work, using readily-available cable. While the desired condition (meaning the M.I.T. version) cannot be exactly met, the losses are not significant."

As we shall see, he understated the condition and overstated the result.

Next, to complete this antenna, we must add a length of radiator at each end because the antenna would not be long enough otherwise. This is because the 66% velocity factor of the inner dielectric results in a total length of the stubs, end-to-end, of only 85.5 feet (on 3.8 MHz) ... thus the outer shield is only a part of the actual antenna, whose length is a free-space half-wavelength, minus approximately 5% for "end effect." In other words, for the correct total length of the antenna, we multiply the free-space length by 0.95. At 3.8 MHz, a free-space half-wave is 129.5 feet and 95% of that is 123 feet ... so, to make that 85.5 foot piece of coax long enough, we must add the difference between that and 123 feet. That's 37.5 more feet, or 18.75 feet at each end.

The ladderline Wysall used for the length extensions enhances the bandwidth of an otherwise thin-wire antenna. Although he may not have added the ladderline specifically for this reason, and perhaps did not separately analyze the influences of (1) ladderline and (2) the coaxial stubs, it appears that he gave all

the bandwidth-improvement credit to the stubs ... which is not true, as we shall see.

Now, let's dissect each of the claimed features:

1. Bandwidth: The perfect antenna, with infinite bandwidth, would radiate all power fed to it by the time it reached the ends of the radiator ... hence, no out-of-phase reflected current returning to the feedpoint to cause reactance in the antenna impedance, and the perfect antenna would be, in effect, a broadband transformer matching the feedline at all frequencies to the 377-ohm impedance of space. The quarter-wave stubs of the coaxial dipole, which change reactance with frequency in opposition to the reactance change in the antenna, are thought to cancel antenna reactance, leaving only resistance. However, a closer look will show that the two high-impedance open ends of the stubs are in series, thus providing a doubly high reactance that appears across and in parallel to the antenna feedpoint. The results are:

(a) The parallel reactance obtained by the stubs is too high to effect useful cancellation of the series antenna reactance.

(b) Even if the stub reactance were to cancel the antenna reactance, practically no reduction in mismatch to a 50-ohm feedline would result because reactance cancellation by parallel circuitry raises the low series antenna resistance to the much higher parallel circuit equivalent resistance, resulting in approximately the same mismatch caused by the uncancelled reactance.

For real numbers and a schematic analysis, see reference #2 at the end of this chapter ... and much additional confirming evidence in the other articles referenced.

Meanwhile, you can conduct a simple test, which will open your eyes:

First, if you're using a coaxial dipole with simple wire end extensions, measure and record VSWR at regular frequency intervals across the band. Next, clip open the inner conductor of the coax in the center, at the feedpoint. This disables the stubs and leaves only a plain dipole, made of the outer shields and the wire extensions. Now check VSWR at the same points again and you'll get virtually the same readings. With no stubs, why the same bandwidth? Because, as stated in subparagraph (a), the reactance provided by the stubs is too high (meaning the susceptance is too low) to provide any useful reduction in off-resonance antenna reactance. If you're using ladder line for the end extensions of your coaxial dipole, the intrinsic bandwidth observed from your VSWR vs. frequency measurements will be greater than that obtained by using single-wire end extensions but, here again, you'll find a negligible difference between having the stubs connected or disconnected.

2. 1.5 dB gain (over a dipole). Antenna gain results from adding the radiations from two or more dipole elements (an array), or by using one or more parasitic elements to influence radiation from the array in a concentrated direction. The coaxial dipole is none of these. Since it simply comprises a single dipole element, it has the same radiation pattern and "gain" as a simple dipole.

3. Has a built-in balun. The two inner ends of the shield provide the same kind of balanced feedpoint seen in any dipole. Therefore, while it may not "need" a balun, it would need it to the same extent that any other dipole would. Saying that it has a "built-in" balun implies that the 1/4 wave stubs function as "bazookas" (the real bazooka is a type of balun) ... but there are no bazookas in this misnamed antenna. Look up the bazooka in any antenna handbook — you won't find it in a coaxial dipole.

4. Provides harmonic attenuation. Since the coaxial dipole is electrically similar to a folded dipole, it acts like one in attenuating only the even (not odd) harmonics.

5. Lower noise factor. The vinyl sheath may lessen local precipitation static, but will reduce no other type of noise, not even atmospheric static.

6. Has directivity. The directivity is no different than that of any other simple dipole.

For a complete treatment of the "double bazooka," see Walter Maxwell:

1. *Ham Radio Magazine*, August 1976, pp. 46-59.
2. *QST Magazine*, September 1976, p. 29.
3. *73 Magazine*, December 1978, pp. 182-190.

SOME SPECIAL ANTENNAS

SLOPING ANTENNAS

There seem to be two distinct categories of hams using slopers, (1) those who swear by them, and (2) those who swear at them.

Since it would be reasonable to assume that, if half of them work well the other half have missed a critical specification. Let's take a good look at these slopers and see if we can figure out what makes 'em tick. First, there are slopers and there are slopers, so we need to categorize them:

1. Most common is the quarter-wave sloper, known paradoxically as a "half-sloper."

2. Also confusing, the half-wave sloper is known as a "full-sloper." As you can imagine, it would be easy to think of the half-sloper as a half-wave antenna and the full-sloper as a full-wave antenna, so the terminology is a little confusing and the above definitions should be kept well in mind. These two types are different, though. with the half-sloper being by far the most common. So we will examine it first, following this with a description of the full-sloper, plus some additional variations.

Basically, the half-sloper consists of a 1/4-wavelength conductor, which is operated in conjunction with the metal mast or tower that supports it. It is indeed important to recognize that the tower is an electrical part of the half-sloper, and unawareness of this fact is a frequent cause for disillusionment with this antenna. The half-sloper is fed with 50-ohm coax at the point where it is attached to the top of the tower. The sloping wire is of course, insulated from the tower up at the top. Then, the center conductor of the coax is connected to the top end of that sloper wire, while the outer shield braid is connected to the tower or mast up there. In addition, the coax must he taped to the tower or mast all the way to the bottom ... no further electrical connections between the braid and the tower, though ... just a firm physical mating of the coax to the tower. Of course the sloping wire must be insulated from the ground at the bottom end, too.

Next, ground the tower or mast well (a poorly grounded tower often causes failure of the sloper). Remember a concrete is basically an insulator, so you must connect the bottom of the tower, using a heavy conductor, to a good ground rod. To be preferred is a good radial system also. Since a 1/4-wave antenna is fed at a current point, the current point in this case is at the top, which is desirable. Although the sloper does not have any gain to speak of, it does have some directivity in the direction of the slope, a characteristic that can be useful in favoring certain DX areas. Another advantage of the sloper is that it is quieter than a vertical as a receiving antenna ... that is to say; it is less responsive to man-made and atmospheric noise than a vertical.

In order to arrive at an optimum half-sloper (1/4 wave), Doug De Maw, Technical Editor Emeritus of *QST*, took a very practical approach, one which is quite possible for the average ham — he simply constructed a scale model of his 50-foot Rohn tower, complete with antennas.

He used a piece of copper tubing to represent his Rohn 50-foot tower, and a sheet of aluminum for the ground plane. He imitated the three-element Yagi on top with a model made of welding rod ... and he made his sloper with #28 wire. For his test equipment, Doug used a Kenwood TS-700, a Bird wattmeter and a diode type field-strength meter. The transceiver was used to serve both as signal source and to check directivity by tuning in various 2-meter repeaters in the area. The scaling, understandably, was not precise, but it proved to be very practical, as far as real results were concerned. In fact, when the 144 MHz model was scaled up to full size for HF, results were within 10% of those observed with the model. Here, from scale-model observations confirmed in actual operation on HF, are the meaningful conclusions:

1. Results were best when the point of attachment to the tower was approximately 1/4-wavelength above ground.

2. The angle between the wire and the tower had a marked effect on VSWR.

3. Other conductors attached to the tower were very important and became a definite part of the sloper system. For example, removing the triband Yagi raised VSWR from 1:1 to 4:1. Guy wires and other slopers had a similar effect. An array of four half-slopers, spaced at 90-degree intervals around the tower made it

impossible to get the VSWR below 5:1 on any of them. The interaction was severe with only two slopers on the same band. Also, guy wires had to be broken up with insulators to form non-resonant segments, minimizing VSWR problems and preserving the desired radiation pattern. By the way, this breaking up of the guys is important to any type of antenna using towers and/or guys as antenna elements. I have seen frustration result from trying to use towers as folded unipoles, half-delta loops gamma- or omega-matched shunt-fed towers, etc., when breaking up the guys would have made all the difference. One such antenna that I use for 40 Meters might not get out of the back yard if I didn't have the guys broken up well.

4. The quality of the ground system affects not only the VSWR but the efficiency of the antennas. When De Maw removed half of the aluminum ground plane from under the 144 MHz model, not only the VSWR changed, but field strength from the sloper went down.

5. Under normal conditions, 1:1 VSWR is obtained by (a) moving the wire at the top up or down the tower a little, (b) changing the angle between the wire and the tower, or (c) both.

6. The wire needs to be slightly longer than the calculated value to give the best match for 50-ohm coax.

7. The radiation pattern is slightly stronger in the direction that the wire slopes.

8. The radiated wave is essentially vertically polarized.

9. Optimum angle between tower and wire is 45 degrees.

10. Maximum angle between tower and wire is 50 degrees. If the wire is so long that the angle must be greater than 50 degrees, it's better to maintain a maximum of 50 degrees, bring the bottom end of the sloping wire close to the ground and then run the excess along parallel to and just a few feet above the ground.

Now for the full-sloper which, again, is 1/2-wavelength long. It is really a center-fed dipole, with one end at the top of the tower and the other end down near the ground. This gives it a combination of both vertical and horizontal radiation characteristics, with a lower radiation angle than that of a regular horizontal dipole, and some directivity in the direction of the slope. It does not rely on the tower being part of the antenna. Therefore, it's simpler and easier to tune. However, you still need to break up the guys, to prevent disturbing the radiation pattern. The full-sloper is fed in the center (normally with coax), so there is the problem of making the feedpoint mechanically strong, to cope with strong winds whipping the feedline.

One other thing: The full-sloper needs a taller tower, if we are to have an angle between wire and tower of no more than 50 degrees. For example, a full-sloper for 80 Meters needs at least 70 feet of tower.

Getting beck to the half-sloper (1/4-wave type), one way is to use two slopers, one for 40 and one for 80 Meters. Now. I know I have said that two or more slopers on the same tower can cause interaction problems. However, that reference was to two slopers on the same band ... and it becomes a different game with slopers on two different bands. Even so, it takes little bit of experimentation to get them properly oriented. Here's the procedure for getting them to work together:

1. Start with the 80-meter wire, making it about 65 feet long. Next, work for the lowest VSWR by moving the location of the bottom end around and varying the amount of slack in the sloping wire (thus varying the angle between the wire and the tower). These things can make quite a bit of difference in the VSWR. Probably, many hams have put up a sloper meeting all the basic requirements, observed still-high VSWR and given up, when a little more patience with the tuning procedure would have done the job.

2. Next, start adjusting the 40-meter sloper. It should be about 33.5 feet long and the bottom end should be moved around the azimuth about 45 degrees away from the 80-meter sloper. Then, as with the 80-meter wire, vary both the position of the bottom end and the slack in the wire for lowest VSWR.

3. Now check to see if this has changed the VSWR on the 80-meter wire. If so, adjust the 80-meter wire for best VSWR, using the same procedure as before, then go back and forth between the two in this manner, just as you would in adjusting 40- and 80-meter dipoles to operate on a common feedline. When you get both to show lowest VSWR at the desired operating frequencies, the 80-meter wire should show no more than 3:1 VSWR at the extreme upper and lower frequencies on the band edges, and the 40-meter wire should cover that whole band without going much over 1.5:1. This brings up an important point: If you use a tube-type rig, there is no reason why you cannot work all of both bands, as long as the rig will load up. On the other hand, if you have

a solid-state rig, the story is a bit different. These rigs, of course, have fail-safe circuitry, which turns the output power down as the VSWR goes up. When using a solid-state rig, then, it is advisable to add a transmatch. The rig will see 50 ohms at all times and will happily dump maximum power into the antenna system. The VSWR on the feedline will be as high as ever, but if it is no more than 10:1, you have no problem and the fellow receiving it will never know the difference.

One related point here is that tuning of the sloper, when using a transmatch, is less critical for anyone who realizes (and it is true) that, when resonated with an antenna tuner, an antenna does not have to be of resonant length to radiate with good efficiency.

There are other variations of the sloper: For example, you can use two wires of equal length, with a proper angle between them, to form a sloping "V" antenna. In this case, the two wires may be fed, where they converge at the top, with balanced twin-feeders and a transmatch, which will afford a very efficient transfer of power to the antenna over a considerable range of frequencies.

You can also make a sloping W8JK or ZL Special beam by having two sloping wires 1/2-wavelength each and feeding one of them in the center, then connecting that feedpoint to the other feedpoint by using a piece of twin-lead and twisting it just a half turn in order to feed the second antenna element in the proper phase relationship to the first. Understandably, getting one of these to work takes a bit more doing.

So, we have covered the half-sloper, which is a 1/4-wave, the full-sloper, which is a 1/2-wave, a combination 80/40-meter half-sloper system, a sloping vee, and sloping W8JK's and ZL specials. We've also thrown in the usual plug for avoiding "VSWR fright."

THE DDRR ANTENNA

DDRR is not exactly a household name, even among amateurs. As a matter of fact, it is not easy to remember whether it is DRRR, DDDR or something in between (which it is). DDRR stands for "Directional Discontinuity Ring Radiator" ... and that is even harder to remember. As a matter of fact, one of the experts, Dr. John S, Belrose, VE2CV, says the name is not appropriate at all, and that it should be called the "HHTL," signifying "Hula Hoop Transmission Line." As we proceed, the reasoning behind this title will become more apparent.

The DDRR is an example of the current trend — searching desperately for antennas which can function reasonably well in the restricted space available to hams today. Many such miniature antennas are better known for converting RF energy into heat than for transferring the power efficiently as a useful signal. As we all know, although most other aspects of ham radio have been successfully miniaturized in spectacular fashion, ham antennas have stubbornly resisted the trend ... however, although you still don't get something for nothing, and there <u>are</u> some compromises to expect, the DDRR is one small antenna which works, to a degree.

To begin, I will describe the antenna physically. There is a great deal of information available to assist you in building one, and I will give you some easy-to-acquire references at the end of this discussion, but first, let's see what a typical DDRR looks like:

For 40-meter operation, picture a piece of 2"-diameter tubing bent into a nine-foot diameter circle, supported 11 inches above a highly conductive ground plane. One end of this tubing is bent at a 90-degree angle down to the ground plane to form a post 11 inches high. The other end (of the circle) is only six inches from this post, but connected to ground through a wide-spaced, high-voltage variable capacitor. This whole nine-foot circle is supported by four insulated posts. Ideally, the "ground" under this ring would be a solid sheet of metal; however, practical application would dictate something like fine-mesh chicken wire. The vertical post formed by the 90-degree bend is bonded to this chicken wire with a flange and a metal plate, perhaps 10 inches square. The antenna is fed with 50-ohm coax, the shield grounded to the 10-inch square metal plate, and the center conductor tapped up the metal post, if necessary, onto the horizontal part of the tubing, wherever you find the 50-ohm resistive point, and the capacitor at the other end of the circle of tubing is tuned to resonance at the desired frequency. The proper tuning procedure starts with the capacitor wide open (minimum capacity) and the physical length of the tubing (including the vertical post) adjusted for resonance at the top end of the band. Then, with the capacitor fully meshed (maximum capacity) the antenna should resonate at the bottom of the band, thus allowing to cover (for example) all of the 40-meter band. It should be emphasized that the DDRR is not basically a multiband antenna. However, it is possible to construct a ring for each band, placing the rings around one another in concentric fashion. Indeed, this DDRR was originally designed to be used in the multiband configuration on a U.S. Navy ship. Also, for single-band operation, the horizontal part of the antenna can be in the form of a spiral.

It was invented by J.M. Boyer, working for Northrup Corporation, and the patents covering the DDRR are assigned to Northrup.

Let's see how and why this antenna radiates RF: It can be best understood when viewed as a <u>very</u> short vertical, with all of the horizontal parts serving as "top loading," to provide a quarter-wave resonant length. The horizontal part radiates very little. When you consider it as a one-wire transmission line quite close to a highly-conductive ground plane, it is obvious that, with the flat-top so close to the ground plane, considerable RF power will be absorbed and very little radiated, and when you consider that the radiation resistance of the very short vertical portion is less than one ohm (typically), you can expect a pretty inefficient antenna. Its principal justification is physical convenience. Its low profile allows it to be used as an invisible antenna on the roof of an apartment building, for example. It can also be used for, say, 40 Meters on top of a large van, by making it rectangular, so that it looks like a luggage rack.

I have a friend, Wayne Lynch, K5WL, who has been reasonably successful with this antenna on the roof of his van, although he recently switched to the "bugcatcher."

Now, let's see, first, how we tune this antenna and, second, how we match it to the feedline:

First, tuning is fairly simple. The variables are:

1. The height of the ring above ground (this, of course, also determines the height of the vertical post).
2. The cross-sectional diameter of the tubing used.
3. The length/cross-sectional diameter ratio of the tubing.
4. The value of the tuning capacitor.

I say that this process is very simple because the dimensions are available in convenient tables. However, it is not all that simple, because the dimensions are critical and sensitive to the environment.

So, each tuning job is a custom affair. The best way to tune this DDRR is to start with the recommended dimensions and fine-tune the antenna with a grid-dip meter, lightly coupled to the vertical post. It is emphasized that, when the antenna is being tuned, the feedline should not be connected until needed. This results in a perfectly resonant stub.

Thereafter, it will be much easier to match the feedline to it. Matching of the feedline is the easiest part, because the resonant antenna (stub) will be purely resistive wherever you tap it, so all you have to do is ground the shield and just move the center conductor of the coax up the post and/or along the horizontal tubing until you find a VSWR of 1:1.

For an antenna that is not exactly a household name, there certainly is wealth of material available. These sources are listed below, and I recommend in particular #7, by Dr. Belrose as the one which is probably the most authentic and objective. Accordingly, it is neither overly optimistic nor is it negative, but it is intended to remind you that you don't get something for nothing. Hams are always looking for a panacea, as far as antennas are concerned, but those things are hard to find!

1. The first of which I am aware was titled "Hula-Hoop Antennas: Coming Trend," by J.M. Boyer, *Electronics*, January 11, 1963,
2. "A Practical DDRR Antenna," by W.E. English, *73 Magazine*, June 1970
3. Also by W.E. English, all necessary material and construction data for DDRR antennas, 160 thru 2, *QST*, December, 1971
4. Next, an article by Robert B. Dome, W2WAH, a complete mathematical treatment of the DDRR. *QST*, July, 1972
5. This was followed by a two-part treatment by the inventor, J.M. Boyer, some 12 pages of very useful information, *73 Magazine*, August & September 1972
6. "DDRR For Your Mobile," by Raymond Powis, W5UKL, *73 Magazine*, May 1977
7. "Transmission-Line Low-Profile Antennas," by Dr. J. S. Belrose, *QST*, December 1975
8. The last two editions of the "ARRL Antenna Handbook." Here again, all constructional details are included.

THE BEVERAGE ANTENNA

Here's how the "Radio Engineers' Handbook" by Terman describes the Beverage antenna: " ... a form of nonresonant antenna used in the reception of long-wave signals. It consists of a wire ranging from one-half to several wavelengths long, pointed in the direction of the desired signal and mounted at a convenient height (usually 10 to 20 feet) above earth. The end toward the signal is grounded through an impedance approximating the characteristic impedance of the antenna when considered as a one-wire transmission line with ground return, while energy abstracted from the radio wave is delivered to a radio receiver at the end farthest from the signal source.

"The wave antenna abstracts energy from the passing waves as a result of the wave tilt that earth losses produce in vertically polarized low-frequency waves traveling along the surface of the ground. When the wave is traveling in the direction of the wire toward the receiver, the currents induced in the different parts of the wire all add up in phase at the receiver because the currents induced in the wire travel with the same velocity as the radio wave and they keep in step with each other. When the wave travels in the opposite direction, the energy builds up as the terminated end is approached, but the terminating resistance absorbs this energy, and there is little or no effect on the receiver because, although the various induced currents are more or less in phase at their point of origin, they are initiated at widely different distances from the receiver.

"The wave antenna (which is what the Beverage is) has marked directivity in the horizontal plane, and this can be still further improved by arranging several wave antennas in a simple array. Since the wave antenna is nonresonant, it can be used to receive, simultaneously, signals of different wavelengths, provided that the transmitters (of such signals) all lie in the same general direction.

"The wave antenna is suitable only for reception. In transmitting, the earth losses are so great compared with the radiated energy that the low efficiency more than counterbalances the directivity obtained."

So says Terman.

Does this antenna have a place in the modern ham's setup? Well, yes and no. If you are an 80/160-meter DXer and have the room, the answer is definitely yes. High noise levels and weak signals are a way of life on 160 Meters in particular, and although loops and other low-noise antennas have been tried in many varieties over the years, nothing seems to beat the Beverage for weak-signal reception.

Of course, the big problem for most of us lies in the size of our real estate. A Beverage antenna, to be effective, should measure at least a full wavelength. When you account for end-effect et cetera, this means that for 160 Meters, the wire must be at least 166.6 Meters long. When we translate that to feet (multiplying by 3.281) we get 546.8 feet at 1.8 MHz. In addition, a first class DXer would want several of these, oriented in favorable directions.

To the average city resident this would, of course, be inconceivable, but a surprising number of rural-type hams do realize some or all of these objectives. In my case, I live in the country and although my few acres are still not enough, I live adjacent to a considerable stretch of government land, which is not being used for anything. This allows me to run one Beverage which measures more than two wavelengths (on 160). I have only the one, but its direction is northeast/southwest. I have not yet been able to terminate it, so it is bi-directional ... and it suffers in performance when compared to the terminated unidirectional version.

Beverages shorter than one wavelength do not work as well, but some improvement is better than nothing, so if you have enough room for a shorter one, it's always worth a try.

I should mention that 160 Meters is the highest frequency range in which the Beverage is normally considered to be at maximum effectiveness. Sometimes it seems to work quite well on 80 and 40 Meters, but this is the exception rather than the rule because, normally, the higher frequency waves come in at higher angles and with changing polarization, because

they are reflected from the ionosphere. On the other hand, this Beverage, or wave antenna, likes waves which come in at a relatively low angle. These low-angle waves tend to almost follow the contours of the ground, thereby keeping their polarization in one constant plane, rather than turning it over.

An unusually comprehensive and convenient reference is available for the Beverage. Some of you may remember the excellent article in *QST* for January 1982. Not only does it feature some up-to-date descriptive material by Doug DeMaw, Technical Editor (S.K.), it also includes the original article from *QST*, 1922! This original version has been lightly edited for style, tense and terminology, to make it consistent with modern-day technical language, and the diagrams, curves, et cetera, have also been revised to make them more readily recognizable today. Nothing else was changed. The spirit and impact of the original article have been retained.

This antenna was originally known as the "Wave Antenna," becoming known later as the Beverage. It was developed by Dr. H. H. Beverage, Chester Rice and R.W. Kellogg of the General Electric Company. It is covered by patents. It was first brought to the attention of amateurs by Paul F. Godley, a well-known broadcast consulting engineer. Paul described the Wave Antenna in his report on the reception of American amateurs at Androssan, Scotland.

In his original article, Dr. Beverage presents the theory behind his antenna somewhat differently, but in a manner which is compatible with Terman's description. I quote Dr. Beverage:

"If a wire is suspended in space, it has a certain capacitance and inductance per unit length, which may bear a definite relationship to each other. This relationship may be expressed as: the reciprocal of the square root of LC is equal to V, where V is a constant. This constant is the velocity of light.

"If a larger wire is used, or if two or more wires are used instead of one, in the ideal case the inductance decreases in the same ratio as the capacitance increases, so that L times C is always a constant. This means that, for the ideal wire, the currents induced in that wire will always travel along it at the velocity of light, independent of the size or number of wires.

"A Beverage antenna needs to be supported at several points and must run horizontally within a few feet of the earth. The effect of the supporting insulators and the proximity of the earth is to increase the capacitance in a greater ratio than the inductance decreases, so the velocity of the currents in a practical wire is always somewhat less than the velocity of light. On short wavelengths, however, the velocity approaches very close to the velocity of light, generally between the limits of 85% and 90% of the velocity of light for 200 Meters (1.5 MHz), depending on the size and number of wires."

Dr. Beverage's original article goes into much detail. He describes both one-wire and two-wire versions. There are graphs showing directivity patterns for both terminated and unterminated antennas. There is also a set of curves showing the effect of height above ground on velocity factor.

He concludes his article with some actual reports on performance:

"Two 200-meter Wave Antennas were erected at Belmar, one running west from the station and one running south. Listening on these antennas showed marked directive properties, as expected. The reception from the West was excellent, great numbers of Midwest, Southwest and West Coast CW stations being heard without interference from the first and second district stations. On the 360-meter broadcast station wavelength, very good results were experienced in eliminating interference, particularly when using the antenna for West Coast reception and cutting out New York and Schenectady interference. Station WOC at Davenport, Iowa, was received particularly well on the Wave Antenna at times when the reception was impossible on the vertical antenna, owing to local interference."

Those are some representative portions of Beverage's very comprehensive article. He provides a great deal of data on design and construction of the antenna. His description might discourage you from using anything but the heaviest wire for the antenna. Actually, for amateur use, it would be hard to tell the practical difference between results obtained with the heavy wire and, say, 20-gauge wire. Some-

times, when you would really like to have the wire practically invisible (for obvious reasons), you can use very light wire and do quite well.

There is another area, however, where you cannot get away with compromise: Wherever the wire is supported, it must be supported with quality insulators. The success of a wave antenna depends upon the waves being allowed to travel along the wire unimpeded by discontinuities or dielectric losses. Also, the terminating resistor at the far end should be connected to at least a good ground rod and, better yet, to some ground radials.

At the end of the Beverage article, DeMaw adds his own comment and describes a Beverage, which he operated some years ago and which comes closer to a typical ham setup. The antenna was 1,500 feet long, single wire, and terminated with a 300-ohm resistor, connected to 16 fifty-foot radials buried in the ground. He also used a home-brew transformer to match the antenna to the input impedance of his receiver. The terminated end of his Beverage was toward the northeast, for working European DX. The transmitting antenna was a 60-foot vertical with center loading and 20 radials, each 80 feet long. Reminding you that this setup was for 160 Meters, listening with the Beverage brought in signals which were two S-units above the noise level, when the same signals came in on his vertical down in the noise, virtually impossible to copy. A significant benefit from a Beverage headed northeast was effective rejection of heavy static in noise fronts in the Gulf of Mexico area of the southwest. Again, when listening with his vertical, the noise from those fronts was very strong.

And last, after describing some of the ways of doing it right, here are a few reasons why mine has not come up to its full potential:

1. The far end of my Beverage is on government land. This has prevented me from putting in a termination or ground radials.
2. For the same reason, my wire is running through trees and is not supported by good insulators.
3. Also for the same reason, the wire is not in a perfectly straight line ... and this <u>is</u> another requirement for the Beverage.

Again, the entire story, in great detail, can be found in *QST* for January 1982.

THE FOLDED UNIPOLE

When the subject of vertical antennas comes up we think of 1/4-wave series-fed verticals, trapped verticals, shunt-fed verticals and gamma or omega-matched verticals ... but there is another vertical, not necessarily unknown, but certainly less known, and apparently overlooked by the majority. This is somewhat puzzling, when you consider some of its advantages.

First (and quite significant) is the fact that it is a higher-impedance antenna. Typical impedance at resonance is in the 50-/150-ohm ballpark. A 1/8-wavelength folded unipole would have an impedance on the order of 50 ohms, as compared to less than 10 ohms for a conventional vertical 1/8-wavelength high. Note: It should be added that the feedpoint impedance of the folded unipole increases as the square of the number of "folds," or added parallel conductors.

In addition to the higher feedpoint impedance, the folded unipole design distributes the current up the vertical more evenly, rather than concentrating it near the ground, where absorption in the ground would cause more losses and lower efficiency ... thus, the folded unipole offers dual benefits:

1. Higher input impedance, which is easier to feed and/or match.

2. Higher efficiency because of fewer ground losses ... so much so that the antenna will perform respectably with no radials — although, of course, a good radial system will add measurably to its performance.

My first experience with this kind of antenna came over 30 years ago, when I was a broadcast engineer. I knew very little about antenna theory at that time, and when I was learning about antennas largely by osmosis, I saw my first folded unipole and found it to be both interesting and practical — practical especially because it got the job done for so much less money. The conventional series-fed vertical used for commercial broadcasting is more expensive for several reasons:

1. The base insulator, designed to support the considerable weight of the tower was expensive.

2. A full complement of 120 radials requires (depending on frequency) some 20,000 to 50,000 feet of #10 soft copper ... quite an item even in those days.

3. To match the 50-ohm coax to the complex impedance of the tower (they were almost never resonant), a matching network was usually located in a "dog house" at the base of the tower, another item of considerable expense.

Compared to this, back in the old days you could erect a folded unipole for a faction of the cost (eventually the FCC made 120 radials a must, though, which closed the cost gap).

Well, several years ago I became interested in developing an all-purpose antenna for the many who wanted to work all the HF bands but lacked the real estate to accommodate the required antenna systems. I went through the various accepted vertical and horizontal configurations normally used on the ham bands with only moderate success. For one thing, the average ham would not be able to afford the tall tower needed for a vertical on 160 Meters.

On the other hand, a horizontal type for all the bands took up too much room and the various compromises suggested to reduce size just didn't get the job done. I went through a number of experiments that were, for the most part, discouraging. Then, suddenly, I remembered the old folded unipole. Since I was particularly interested in 160 Meters, and since that band has so much in common with the broadcast band, I began to wonder if I shouldn't try it for the ham bands.

Now, the broadcast version used a couple steel arms, crisscrossed at the top of the tower, forming four spokes that stuck out on all four sides a few feet. Wires were dropped from each arm to within a few feet of the ground. The bottom ends of the wires were all tied together with a skirt, but insulated from ground, and this skirt became the feedpoint against ground. The center conductor of the coax was connected to the skirt and the shield was, of course, grounded.

Well, I tried to build something electrically similar that would be both economical end easy

to erect, so the first thing that came to mind was the telescopic "push-up" mast, which comes all folded up in a 10-foot package. These, by the way, are available, among other places, at Radio Shack. They are made by Rohn and come in two grades. Be sure to get the higher-priced one. It has better galvanizing and is much stronger. They come in sizes from 20 to 50 feet. For my original folded unipole, I used the 50-foot version, extended to only 40 feet for more strength.

When I tried to make a folded unipole, however, I found that I couldn't do it exactly like the broadcast version, for mechanical reasons. There was no simple way to put the steel cross-arms on top, and the flexibility of the mast made a mess out of just dropping the wires straight down, so I looked for a way of keeping the electrical characteristics while changing the mechanical arrangement. Since I needed some kind of guy system for the pole, I decided to try incorporating the unipole wires and the guys. I used close-woven nylon for the guys and used the top set of guys to support the wires. This brought the wires down the guys about 20 feet (dimension not critical) and out away from the mast some ten feet or more. Then, the rest of the wire was pulled back into the base of the tower, making the wires form something like a "poor man's conical monopole."

I used four guys (hence four wires). I fastened the wires to the top of the mast electrically by sanding the mast, baring the ends of the wires and clamping them to the mast with a stainless steel hose clamp. To be sure of avoiding future corrosion, I then covered this area with silicon rubber cement. At the bottom, I pulled all four wires together, soldered them together and placed them on an insulated standoff — this became the feedpoint (against ground), for 450-ohm plastic ladderline.

This antenna used 40 feet of mast. In the top of the mast I fastened a 15-foot piece of aluminum tubing, to serve as top loading. The nylon guys can be fastened to anchors no more than 30 feet from the bottom of the mast, or you can tie them to convenient trees, houses, etc.

I chose two different sizes of close woven nylon for the guys, 1/4 inch for the bottom guys and 3/16 inch for the middle end top guys. The 1/4-inch guys are mainly for the erection process. They are strong enough that you can lean your ladder against the bottom 10-foot section safely and proceed to push the other sections up, one by one.

By the way, be very careful handling the pushup mast. If you slip it is easy to pinch and cut your hand. It is a good idea to wear heavy leather gloves ... so if you do slip, it will be the gloves, not you that gets pinched!

Now, for feeding and matching the antenna. I had two choices:

1. I could use coax and tune it at the base. Since this was to be an all-band antenna, it would involve remote relays and/or tuning motors and be complicated and expensive, all of which would be in conflict with my objective, which was a simple, inexpensive but effective all-band antenna.

2. So now was the time to practice what Walter Maxwell preaches ("The Easy Way," chapter l), using low-loss line and matching at the source. This is what I did, and it was so simple; convenient and effective on all HF frequencies that it is really hard to understand why so many put up with the complications and expense of tuning at the antenna.

Using a conventional "T Match" tuner, such as Dentron, Murch, Swan, MFJ or Heath, it is no trick to present your rig with a 50-ohm resistive load on any of the Amateur HF frequencies. For feedline, I originally used the bare open-wire type, however, several years ago, I tested the Saxton 450-ohm plastic ladderline. I found it to be practically as effective as the bare line and easier to use, with these advantages:

1. More compact, about one inch wide, with rectangular holes punched in it to reduce wind loading.

2. Rain and ice can sometimes put you out of business when using the bare stuff, but the plastic line will allow you to touch up your tuning, even with ice on the line, and proceed.

3. You can thread a light nylon in and out of the holes in this line, stretching the nylon tightly to serve as a "messenger cable" and take all the strain off the ladder line itself.

By the way, the impedance of this folded unipole is 50 ohms in the middle of the 80-meter band, but the exact impedance is not particularly important, since it will vary quite widely over all the different bands and frequencies on which it is capable of operating. In

connection with this point, there is one question I am frequently asked: "If the antenna has an impedance of 50 ohms, why do you use 450-ohm feedline?"

Well, as you can begin to see, since the line looks at all different kinds of impedances, its exact impedance is academic. We are interested in just two benefits:

1. Two wires far enough apart not to arc over with the high voltages which are present at some frequencies.
2. A feedline which has minimum loss, so that sometimes-considerable reflected power will have minimal effect ... and coax simply cannot begin to satisfy these criteria.

NOTE: This whole concept is so radical to many that remedial study may be required before one can accept and believe in it. Again, in this case go back and re-read Chapter 1 ... carefully.

One other thing: A feedline approximately 65 feet long will allow your transmatch to present the rig with 50 ohms on any and all HF frequencies you may wish to use (assuming that your tuner was designed to cover from 160 to 10 Meters). If you are forced to use a feedline of another length, you may have to "cut and try" by adding or subtracting a few feet at a time until all the bands tune easily. If you use the antenna only on 40 through 160 Meters, though, the length of the line will not be critical. The frequencies from 20 Meters up are the ones that may act up when your feedline is not the right length

Assembly of this antenna is easy, if you take the necessary steps in proper order. I wrote an article on the antenna for the annual antenna issue of *Ham Radio Magazine*, May 1979, entitled "The Folded Umbrella."

I am now using a somewhat larger version of this antenna, based on a 68-foot tower and using part of the guy wires as part of the "umbrella," with the beam on top serving as top loading. This is an example of the non-critical nature of the antenna, as far as dimensions are concerned. You can make the vertical part any height from 40 feet up and use whatever length is convenient for the umbrella wires. The open feedline and the transmatch take care of the rest.

Of course many will say, "but I just can't get that balanced line into the shack." Well, if you really believe in this antenna you would find a way to get the feed line problem taken care of, but while you are trying to make up your mind, here is a method that will eliminate the reasons not to try it anyway — just put a 4:1 balun outside the shack, terminate the 450-ohm line there, and bring a short piece of coax into the shack. Try to make the coax as short as possible, by all means less than 10 feet.

What I'm trying to do here is remove all those traditional mental blocks about balanced feed lines and tuners, because once you try it and get it working for you, you'll wonder and how you have lived so long with all those traps, coils, multiple antennas and coaxes.

And, if you have just a small back yard, this is still an antenna which will have you in business on all seven HF bands.

In summary, in the folded unipole ("Folded Umbrella") you have an antenna which is:

1. Versatile.
2. Broadband.
3. Easily tuned.
4. Effective with minimal ground system.
5. Without critical dimensions.
6. Simple and inexpensive.
7. Easily erected by one man.
8. Space-saving, considering what it does.
9. DC-grounded.
10. Adaptable to your tower.

Don't expect it to perform like a beam, but it will more than hold its own, at any frequency, compared to virtually any of the "non-gain" types of antennas in general use.

VACATION ANTENNAS

We can put most vacation antennas in one of three categories:

1. Purely mobile ... used mainly when your vehicle is in motion.

2. Mobile/Portable ... used after the vehicle has stopped.

3. Residential portable ... the kind you set up in the back yard after you reach Uncle Joe's home in Milwaukee.

The first type, the purely mobile antenna, will be mentioned only briefly here, since it receives comprehensive treatment elsewhere in this book. In the "mobile antenna" chapter, you will find both the Hustler and the home-brewed "bug catcher" covered in considerable detail.

The second type is the "mobile/portable" antenna, which is deployed only after the vehicle is parked. The very first one of these involves your "purely mobile" antenna, but in a special way. For this setup (just for 40 and 80 Meters), make an extension which can be screwed on top of the regular mast, long enough to double its height. Next, provide a fitting on top of this extension which will allow the 40- or 80-meter resonator to be screwed on top. This antenna will perform much better than the standard model (the whip in the top of the resonator does not have to be retuned). Finally, since you are going to take the rig indoors (motel, etc.), you will need some extra feedline. For this, make two 50-foot lengths of RG58 or RG8X, complete with PL-259 connector on both ends of each. Also, carry several PL-258 double-ended female/female adapters. This arrangement will allow you to take your rig into the motel and connect it to the antenna on the car. Generally, one 50-foot piece is enough, but when you can't get the car close enough to the room, the extra 50-foot piece (and a PL-258 to join them together) will save you.

Next, a popular antenna for trailers and some vans is the multiband vertical. A very practical mount for this type of antenna uses a 2" or 2-1/2" pipe, set up vertically either on the rear bumper of the trailer on the trailer hitch in front. The top end of this pipe should be at roof level, with a hinge arrangement to which you bolt the bottom of the vertical, thus allowing it to be folded down along the trailer roof while in motion. The antenna can be permanently connected to the rig, and within minutes after stopping it can be flipped up and you can be on the air. There are a number of the standard commercally-available multiband verticals which can be used in this manner, and there is one antenna which has no traps (more efficient and more bandwidth) that is ideal for this application — the Butternut. This antenna seems very popular with the retirees who travel around the country, and their signals are, in general, very impressive. Incidentally, the metallic mass of these trailers will serve as an adequate ground plane.

There is another portable antenna used quite a lot in the Southwest, known as the "Hot Tamale," named for W5HT, Paul, who pioneered it in this part of the country. The basic version is simply an end-fed 1/4-wavelength of wire, trimmed for an impedance match with the rig. The trailerite hams use a rubber-shooter and a round lead fishing sinker to shoot a light nylon line up over a tree limb, using the light line to pull up a heavier line capable of pulling up the antenna.

At the trailer, the wire goes through an insulated feed-through and is connected to the rig or a transmatch. This antenna is normally used for 40 or 80 Meters. For working both those bands, there are three methods:

1. Make the antenna approximately a 1/4-wavelength for 80 Meters and put a trap in it for 40 Meters.

2. Using a common feedpoint at the trailer, fan out two wires, one of them 1/4-wavelength for 40 and the other 1/4-wavelength for 80. Keep them separated at the far end as much as possible.

3. You can use just the 80-meter length and a transmatch, allowing you to tune any frequency on either band, plus other bands as well. In addition, the length of the wire is not at all critical when using a transmatch.

There is one other portable antenna which deserves mention because it is so simple, compact and inexpensive that it's a good one to have on hand just for emergencies — it's called the "Zipcord" antenna. Just take an appropriate length of regular AC zipcord and pull the

two wires apart until you have enough to make a dipole for the desired frequency. Then knot or tape the cord to keep it from pulling further apart, and use the balance of the zipcord for the feedline. Prune it to match your rig or you can use a transmatch, but use it "barefoot" only.

And the third category, the "residential portable:"

A good example is the "balcony vertical." A practical antenna to use for this is the Hustler mobile antenna, mast and all. Take one of the ball-type mounts used for mobile antennas and bolt it to an aluminum plate, say, eight inches square. This plate can then be fastened to a balcony rail or window sill with a couple "C" clamps. It's also a good idea to put a bolt and wing-nut on the plate for use as a convenient ground connection — which brings us to an interesting idea for a ground plane to use with an apartment vertical: It is based on the "Slinky" antenna, which uses the coil-type toy as a compact radiator. To use it as a counterpoise (ground plane), simply tune it as you would when using it as an antenna, but place it near the bottom of your balcony vertical to serve as a ground plane. Just connect the center of the Slinky to the wing-nut on the aluminum base plate. Where you put the Slinky ground will depend on your ingenuity. For example, if the balcony has a wooden or concrete floor, lay the Slinky right under the vertical. If the antenna is mounted on a window sill, just lay the Slinky against the wall, on the floor, under the window, or you can even hang it under the eaves.

If you want to use the Slinky as the antenna, put the two coils on two 10-foot wooden dowel rods and suspend them from the ceiling, using vinyl-covered cup hangers. For convenience, and for the antenna to be as inconspicuous as possible, the two elements can be placed to form a 90-degree angle up against the ceiling and in a corner of the room, with the feedpoint of the antenna in the center ... right in the corner. If you use 300-ohm twinlead and a transmatch, you can tune all bands without readjusting the coils. Full details on this arrangement can be found in *QST*, October 1974.

You can also buy the Slinky toy at a toy store and make your own unique vertical for hotel or apartment use. This antenna is known as a "Boinger." It uses a cheap closed-face spinning reel, a weight and some other simple hardware to make an inconspicuous device that drops your Slinky out a 2nd or 3rd story window to whatever length will tune the band/frequency you want. An article giving full details appeared in a non-ham magazine, *Elementary Electronics*. It was actually intended for short-wave listeners, but it is a neat idea.

Another interesting portable antenna was developed by VK5BI, and called the "Suitcase. Antenna." It is constructed of wire wound on 1" PVC tubing. Fully assembled, it is 65 inches long and it operates on 80, 40 and 20 Meters. It is, understandably, narrow-banded and not very efficient, but it is easy to set on the frequencies you want and the fact that it can handle 500 watts will allow you to make up for some of the losses involved. Its maximum dimension when disassembled is 33 inches, so it can be fitted diagonally into a large suitcase. Full construction and operating details were carried in *Ham Radio* for May 1973.

If the portable antenna must be completely invisible, a wire down the chimney and fed in the fireplace may be the concealed vertical you need. An antenna can be laid on a non-metallic roof (using insulated wire), or suspended just a few inches above the roof, where it will still be invisible from the ground. One particularly interesting approach is to use the metal flashing around the ends of the roof (if the roof is non-metallic). A convenient way of connecting a feed wire to the flashing is to use a stiff piece of hardened piano wire, bent into a hook and sharpened to a point. Fasten your feed wire to the hook and then reach out the window and pull the hook into the flashing to make contact, or, where the flashing is more accessible, just secure the feed wire to the flashing with a sheet metal screw. I have used this type of antenna with reasonable success, although you can't expect it to be quite as good as your regular outside antenna, it does surprisingly well.

And, when all else fails, one last resort: Don't forget those two 50-foot pieces of coax that you took along so that you could use your rig in the motel. If, for example, you are staying in an apartment where no outside antennas are allowed, you may have an assigned parking space near your apartment. If the car is parked less than 100 feet away, just use your ingenuity to get that coax from your apartment to the car

antenna — you may be surprised at the ham activity awaiting you.

So, we've looked at three categories of vacation antennas:

1. Purely mobile antennas.
2. Mobile/portable antennas.
3. Portable antennas.

All of these (and others which may be suggested by them) remind me of one admirable characteristic of the ham: He loves a tough challenge. Whether it's QRP, acquiring the Extra Class ticket or surviving a restrictive tower ordinance, the ham will find a way to beat the odds, and taking his radio station with him on vacation is just another challenge.

MOBILE ANTENNAS

First, some theoretical background on mobile antennas; Second, three different practical applications of this theory, comparing advantages and disadvantages for each. Starting with theory, I will make and develop two statements:

1. On HF, considering the short length of coax used for a mobile installation, matching can be accomplished at the transmitter with very little loss, allowing much greater usable bandwidth at optimum efficiency.

2. Comparing two center-loaded whips of equal size, the center-loading coil will display the following characteristics:

a. The coil with the highest Q will present the feedline with the lowest impedance.

b. The coil with the highest Q will present the highest SWR.

c. The coil with the highest Q will be responsible for the narrowest bandwidth.

d. The high-Q version will provide the highest efficiency and the most radiated power.

It follows, then, that an antenna with a low-Q coil will present a higher impedance, thus coming closer to a match with the coax, with greater bandwidth and lower Q — but we pay for apparent advantages with lower efficiency and less radiated power. Now let me point out something that does not seem to be generally known: There are, in matching an HF mobile antenna, not one, not two, but three different resistances to be considered.

First, there is radiation resistance, across which is developed the power actually radiated by the antenna, and the comparison of this power only to the power fed into the antenna system is the measure of the antenna's efficiency.

The second resistance is coil resistance. Now, as is the case with radiation resistance, this is not something you measure with an ohmmeter. Rather, it is the value of a resistor which would consume power equal to the amount lost in the antenna loading coil. There are a number of factors which could contribute to coil loss: wire size, coil diameter, turn spacing, distributed capacity and self-resonance (more on this later).

The third resistance, and the one most overlooked for mobile antenna systems, is ground resistance. Again, you can't measure this with an ohmmeter, but it is equal to the value of a resistor which would consume power equal to that lost in the ground. This loss for a mobile antenna is no less significant than it would be for the vertical in your back yard.

At this point, let me re-emphasize that power losses in coil and ground resistances are totally subtracted from input power, leaving only the power developed across radiation resistance to be usefully radiated. Since the lowest frequency will make a mobile antenna look the shortest, in terms of a wavelength, let's use the 80-meter band as a "worst case" and see just what the efficiency of a mobile antenna can be:

Depending on physical height of the whip, radiation resistance for a typical 80-meter center-loaded whip is in the one-ohm ballpark. This means that feedpoint impedance of the antenna alone (not counting ground resistance or coil resistance) is a combination of that one ohm of resistance and about 3,000 ohms of capacitive reactance, expressed as "1 – J3000." The purpose of the center-loading coil, then, is to provide an amount of inductive reactance (+J3000 ohms) equal to the – J3000 ohms antenna reactance, but opposite in sign, the two reactances canceling and leaving only the one ohm of pure resistance ... the radiation resistance.

This now leads to a prevalent but erroneous supposition that we must match the one ohm of radiation resistance to the 50-ohm coax with a 50:1 matching device — NOT SO! What the feedline actually sees is radiation resistance plus coil resistance plus ground resistance. This means that the input power is expended across all three resistances in series, but remember that the only power usefully radiated is that developed across radiation resistance. Now, let's give these three resistances some values and see what we have:

First, let me point out that with a given whip dimension and coil, the radiation resis-

tance will remain essentially constant, no matter what the coil resistance or ground resistance may be. So, in order to simplify this discussion, let's just stick with that one ohm of radiation resistance (on 80 Meters). Next, loading coil resistance, depending on the Q of the coil and its self-resonant characteristics will vary from about 8 ohms to as high as 31 ohms. One of the reasons for the wide variation is that distributed capacitance in the coil can combine with its inductance to produce a self-resonant circuit at a frequency near the operating frequency, and the high circulating current which results will cause IR losses plus dielectric losses plus radiated losses, all of which waste power, lower the Q and, in an expensive way, provide greater bandwidth and lower SWR. This is, of course, low SWR for the wrong reason.

Next, typical ground resistance for a mobile operation may range from 5-12 ohms. I should mention that it is somewhat less than for a normal home-based operation because, with a shorter vertical, the radius within which the currents return to earth is smaller, and shorter ground-return paths mean less resistance.

Now let's go back to add up those three resistances and see what we get: In the most ideal case, we have eight ohms of coil resistance plus five ohms of ground resistance plus that one ohm of radiation resistance (still on 80 Meters). This totals 14 ohms, so the rig now sees a mismatch, and an SWR of more than 3:1. However, the loss in, say, 10 feet of RG8 coax, even with 5:1 SWR or higher, is less than 0.1 dB.

Since the only power radiated is that developed across the one ohm of radiation resistance, and the total resistance is 14 ohms, the efficiency is 1/14, or something over 7%. I am sure that seems low to you, but you haven't seen anything yet.

The setup I have just described is the so-called "bug-catcher," using a high-Q, air-dielectric coil, so let's look at one of the most popular commercially-available coils, showing a coil resistance (80 Meters) of 31 ohms. If you add to that, say, 12 ohms of ground resistance and that constant 1 ohm of radiation resistance, you now have your feedline looking at a total of 44 ohms. Boy, the SWR is only about 1.1:1 ... isn't that great? Not really. Again, that's low SWR for the wrong reason! Let's see why:

Very simply, the one ohm of radiation resistance is now responsible for radiating only 1/44th of the input power, and radiation efficiency is now 2.2%. This means that, for every 100 watts from the transmitter, this low-Q setup would radiate 2.2 watts of power, 16.5 dB below the transmitter's output. But the high-Q setup, in spite of higher SWR, will radiate over seven watts, a 5 dB improvement, up to 11.5 dB below input power.

Of course, at this point, you're thinking, "But what about that 3:1 SWR?" Remember, we lose less than 0.1 dB in the feedline, so that's no problem. And now you're saying, "But my solid-state rig will reduce its output power drastically when faced with such SWR." That's no problem either — just buy or build a small "T" type transmatch. It will present your rig with 50 ohms, resistive, and use negligible power. Such a system will also allow you to operate on a much wider range of frequencies.

Just one more item: I don't want to leave you with an exaggerated impression of the low efficiency of the mobile antenna. Remember. we were using the 80-meter version as a "worst case," but it's all downhill from there.

As the operating frequency goes higher, the same antenna looks taller and taller (in comparison to a wavelength) and the radiation resistance goes up. For example, if the frequency got high enough for the vertical to look like a quarter-wave antenna. the radiation resistance would, of course, be around 36 ohms. Bearing this in mind, let's try the 40-meter band, using the same whip height we had for 80 meters, as a more optimistic example: First, on 40 Meters, the radiation resistance comes up to three or four ohms and the coil needs about one-third the number of turns. This means a lot less coil resistance. which means much less loss, and the radiation resistance is a much higher percentage of the total resistance seen by the feedline, all of which adds up to higher efficiency, on the order of 10 to 15 percent. In fact, with some top loading and a little extra care in design, 25% efficiency can be readily realized on 40 Meters, and the efficiency goes right up with frequency until, with the same whip, you can attain upward of 70% on the 10-meter band.

And here are three different mobile antenna systems, one of which should fit your particular requirements:

First, although I may have seemed to infer otherwise, a system such as the one using Hustler components has a definite place in this group, because it is simple, does an acceptable job and is a good choice for the occasional user (vacations, etc.). Just strap the base to the bumper, seat the mast, screw on the coil, connect the coax and slide the whip in or out of the top for the lowest SWR at the desired frequency. No fuss, no muss — it will work. I have worked all continents this way. There are more efficient systems but it is adequate.

Details for the second method can be found in the "ARRL Antenna Book. " It shows how to use a high-Q center-loading coil plus a coil or capacitor (depending on the band) for matching at the base of the antenna. This is more efficient than the Hustler and for a single-band, limited frequency spread, an excellent choice. If you want to work your favorite net and stay on that frequency all the time, this system is for you, but if you want to work other bands on random frequencies, then getting out of the car and into the trunk to tune the base of the antenna will get old in a hurry!

The third way gives you both maximum frequency flexibility and optimum efficiency, and here's how you do it:

1. Get a bug-catcher coil with enough turns to accommodate the lowest frequency on which you plan operating. ("Bug catcher" is a high-Q air-dielectric coil. The name is supposed to have originated in Texas!).

2. At the bottom of the coil, fasten a clip lead long enough to reach easily to the top of the coil and put a clip on the free end.

3. Determine experimentally how much of the coil to short out to leave enough turns for the desired band. Mark this point on the coil with bright red nail polish and repeat for each band which you plan using. If you also want to work CW or if you want to cover all of the 80-meter band, you will find it necessary to tap at two different places on the coil for that band, but for the average setup, this should not be needed.

4. Use RG8 or RG8X feedline and install a small transmatch at the rig. The proper tap on the center-loading coil will have established the lowest SWR attainable without a transmatch, on the order of 2:1, 3:1 or more, but the transmatch will easily convert this to a 50-ohm resistive load for your rig, and the power lost in the transmatch will be insignificant.

I have used all three of these systems and each has served its purpose. However, I enjoy working all the bands, both phone and CW, so my current setup includes both the bug-catcher and the transmatch. If you are interested in this option, I will be happy to send you details on hardware, installation and tuning.

BEAM ANTENNAS

THE W8JK ANTENNA

One of the most interesting things about the famous W8JK antenna is the aura of history which surrounds it. First, John Kraus, its inventor, is one of the giants of ham radio and, indeed, of electronics in general. John Kraus is W8JK, Professor Emeritus of Electrical Engineering and Astronomy at Ohio State University, where he has been on the faculty since 1946. He received his Ph.D. in Physics from the University of Michigan in 1933. He has written literally hundreds of technical articles, plus such books as "Antennas" in 1950, "Electro Magnetics, 2nd Edition," in 1973, "Big Ear" in 1976, and "Our Cosmic Universe" in 1980. Dr. Kraus is also the inventor of the helical beam antenna, the corner reflector antenna, the backward-angle-fire-grid antenna, the W8JK and other close-spaced arrays, multi-wire doublets and others. Dr. Kraus is a Fellow of the IEEE and a member of the National Academy of Engineering. He has been a licensed amateur since 1926.

Next in our history, we must include Dr. George H. Brown of RCA, whose classic papers in the "Proceedings of the IRE" in 1937 profoundly influenced the design of commercial broadcast antennas from that day to this. Before that time, it was generally conceded that proper spacing between the driven element and the reflector of a two-element phased array should be at least 1/4 wavelength. However, Dr. Brown showed that smaller spacings might be better. The key to his discovery was in calculating antenna gain for a constant power input, instead of considering antenna current to be constant as had been done previously.

As soon as John Kraus saw Brown's paper, he was intrigued with the possibilities offered by the idea and he lost no time in designing the first W8JK beam, with two horizontal dipoles driven in opposite phase, at the unprecedented small spacing of 1/8 wavelength. This was the first practical, popular antenna to use such closely spaced elements and, when John checked his first prototype, he was quite pleased to see that the antenna did, indeed, provide the amount of gain that Dr. Brown had predicted mathematically. Kraus then wrote a series of articles on the antenna for *QST*, "Short Wave World," "Proceedings of the IRE," and a section for his book, "Antennas," published by McGraw-Hill in 1950. Then, in July, 1970, he wrote another article for *QST* and, finally, "A Recap and Update of the W8JK Antenna" for *QST*, June, 1982. His latest article enumerated characteristics of the W8JK, which I now list, and which I will address in more detail later. The characteristics, briefly, are:

1. It can operate well over a frequency range of 3 to 1.
2. It needs no traps or loading coils.
3. No dimensions are critical, since antenna and feeders are resonated as a system.
4. It can be operated horizontally or vertically for optimum pattern, as required.
5. It is ideal for finding open round-the-world communications paths.
6. It has, theoretically, zero radiation off the ends of the elements.
7. It can be fed with inexpensive, low-loss twin line.
8. It is compact — for example, a 20- through 6-meter version is 24 feet.

To visualize the simplest version, think of two parallel wires, 1/2 wavelength each, spaced 1/8 wavelength apart. These wires can be voltage fed from one end or they can be fed in the center. In either case they are fed in such a way that currents in the two wires are flowing in opposite directions. This results in cancellation of fields between, and above and below the two wires, as well as off the ends of the two wires, with a gain of approximately 4 dB (compared to a dipole at the same height). This gain is in the horizontal plane, broadside to and away from each of the two wires. In other words, the antenna is bidirectional. As a result, in addition to being a compact rotary antenna, it can also be fashioned more simply as a fixed wire beam, tied between the trees. If it's oriented for a northeast/southwest radiation pattern, it will meet most of your needs, especially for DX.

Now let's consider how to feed these two parallel wires:

First, the center-fed version is by far the most popular and practical, so we will concentrate on that method. Just visualize the two

wires as a pair of center-fed dipoles, 1/8-wavelength apart. Next, picture a pair of wires connecting the two center feedpoints. These are not too critical as to spacing and should be bare wires so that it is easy to connect the feedline at the proper point, which is normally halfway between the elements. The next thing is to cross over the pair of wires between the elements. This is necessary to ensure equal and opposite currents in the two antenna elements, resulting in cancellation of fields between, above, below and off the ends of the antenna.

Next, I'll describe what I think is the best overall feed system for the W8JK. If you have read my presentation on "The Easy Way," or if you have heard many of the Antenna Workshop talks, it will come as no surprise, and is just another example demonstrating the soundness of the philosophies expounded by Walter Maxwell. I might add that although John Kraus offers several feed methods, he heartily agrees with this one. It is very simple and effective. Just use a section of 300-ohm twin lead to connect the two feedpoints, and tap this section somewhere near the middle. I say near the middle, because the twisting over of that 300-ohm section may have some slight effect on balance. Also, by moving the feedline closer to one dipole, you can cause the antenna to radiate in one direction only. There are some popular commercially-marketed beams with close-spaced dual-driven elements which I suspect have been at least partially influenced by the W8JK.

The feedline is also 300-ohm twin lead, terminated as follows:

1. If it is inconvenient to bring the twin lead into the shack, just mount a 4:1 antenna balun immediately outside the shack, on the outside wall, maybe up under the eaves, for weather protection. Terminate the 300-ohm line on the antenna terminals of the balun. Then, make up a short piece of coax to run from the balun into the shack ... keep this as short as you can and connect it to the unbalanced input of a good transmatch.

2. The other method is really not too difficult, actually easier in some ways. Simply bring the 300-ohm twin lead right into the shack and connect it directly to the balanced output terminals of your transmatch. Incidentally, Radio Shack has a nice feedthrough tube for TV twin lead, with faceplates for both the inside and outside walls. This will do a neat job of bringing the 300-ohm line in.

Either of these methods will give you the ultimate in flexibility, allowing you to present the rig with a 50-ohm load at all frequencies on the 20-, 15-, 10- and 6-meter bands, with high efficiency. This is predicated on an array 24 feet long, with 8.5 foot spacing between the elements.

Gain figures for the array will differ from band to band, but this is a function of the array itself, not the feed system. Here are the gain figures compared to an isotropic antenna:

20 Meters — 5.7 dBi
15 Meters — 6.7 dBi
10 Meters — 7.7 dBi
6 Meters — 8.2 dBi

If you want "real world" figures, subtract 2.1 dB to give you the gain, compared to a dipole.

In his June, 1982 *QST* article, John Kraus discusses antenna environment, showing various heights above ground, as they affect antenna performance. Also he emphasizes the manner in which vertical and horizontal polarizations differ, in marked fashion, at a given height. He recommends, therefore, a beam which can be flipped over for either polarization and, in his newest article, shows how to do this.

As have said before, I try to make these talks useful for the 40-meter band, since we are all interested in more effective communication on this net, so let's look at appropriate dimensions for a fixed-wire W8JK beam on 40 Meters. It would have elements approximately 66 feet long, spaced about 17 feet (1/8 wave).

As usual, you don't get something for nothing, and I must mention a couple things to be careful about:

1. The short spacing between the two elements results in heavy field cancellation between them, which produces heavy current at the center feedpoints. This means that the impedance at the feedpoint is quite low, on the order of four ohms ... and it is a good idea to use heavy wire or tubing for the antenna elements.

2. It follows, then, that there is very high impedance, with resultant high voltages at the ends of the antenna elements, and environment becomes more critical in two ways:

a. Contrary to prevalent opinion, a dipole can suffer from ground losses unless it is high enough above ground and, if this antenna

in particular were too close to the ground, its efficiency would suffer. Efficiency is, of course, the amount of power radiated divided by the amount of power fed to the antenna.

For example, if 100 watts were fed into an antenna with four ohms radiation resistance and eight ohms ground resistance, that input power would be distributed in a total resistance of 12 ohms, with only 1/3 of that radiating useful power. That's an efficiency of only 33.33 percent. Since ground resistance will be effectively diminished with increasing antenna height, improvement of efficiency with height is obvious.

b. In like fashion, proximity of the high impedance/high voltage ends of the elements to metal structures, trees, etc. will have a negative effect on the electrostatic component of the antenna's radiated field. In other words, this antenna should be fairly high and in the clear. It's not the kind you want to string up in your attic! If you're interested in using this antenna, you'll want more detailed information. Fortunately, there's a wealth of material available.

Here is a list of sources:

1. Article by John Kraus, *QST*, July, 1970.
2. Kraus' book, "Antennas," McGraw-Hill, 1950.
3. Article by John Draus, *QST*, June, 1982.
4. "HF Antennas for All Locations," L.A. Moxon, G6XN
5. "Radio Communication Handbook," Volume II (RSGB)
6. Bill Orr's "Radio Handbook" (expensive!).
7. "Amateur Radio Techniques," Pat Hawker, G3VA (RSGB).
8. Any ARRL Antenna Book.

THE YAGI ANTENNA

The Yagi antenna was invented in 1926 by Hidetsugu Yagi and Shintaro. Uda, both of Tohoku University, in Japan. Since then, it has received a tremendous amount of theoretical and experimental attention, and a bibliography covering significant sources on this subject would, in itself, cover many pages.

The Yagi has certainly become the type of beam used most widely by amateurs. It adapts well to the relatively narrow amateur bands, is not difficult to build, and is physically rugged, allowing it to survive weather extremes. Additionally, it is forgiving with regard to design flaws — it is an antenna that wants to work.

I will cover only the most basic two-element version in this chapter. The reason for keeping it simple is that even a two-element Yagi is not really simple. A permutation of the variables involved with only two elements will reveal that possible design combinations are almost limitless in number. Variables include:

1. Boom length.
2. Element spacing.
3. Element size.
4. Type of parasitic element (reflector or director).
5. Mutual impedances.
6. Impedance matching.
7. Desired front-to-back ratio.
8. Desired bandwidth.
9. Desired gain.
10. Compromises involved in achieving #7, #8 and #9.

A Yagi is a parasitic array, just as in the case of phased verticals, for example, except instead of relying on the ground system to provide half of the vertical element, we now have the two halves of each element nicely symmetrical and perfectly balanced, usually in a horizontal plane, for amateur use.

The basic two-element Yagi contains a driven element and a parasitic element, the latter functioning as an element which causes the radiation to be essentially unidirectional. When that radiation is in a direction starting from the parasitic element and going through the driven element in a direction away from the parasitic element, that parasitic element is a reflector. When maximum radiation is the opposite, or in a direction from the driven element out through the parasitic element, that element is then known as a director.

Whether the parasitic element operates as a reflector depends on the relative phases of the currents in the two elements. With the element spacings commonly used (i.e., a quarter-wave or less), the most basic way of making the element a reflector is to tune the parasitic element to the low-frequency, or inductive side of resonance, accomplished, of course, by making it a little longer. Naturally, it becomes a director by tuning it to the high-frequency or capacitive side of resonance, making it a little shorter.

Of course, these things are pretty well-known. Not quite so obvious is the fact that the parasitic element can be tuned to resonance and still perform as either a reflector or director, depending on its spacing from the driven element. In this case, it can provide maximum gain as a director when placed 1/10-wavelength in front of the driven element ... and as a reflector when placed 0.15 wavelength behind the driven element. The director will give slightly more gain (usually less than 1/2 dB) and the reflector will usually provide a better front-to-back ratio.

Let's look at the effect achieved with other reflector spacings:

1. For all spacings under a quarter-wavelength (other than 0.15 wavelength), it is necessary to make the element longer, while at spacings more than a quarter-wavelength, the reverse is true.
2. The director, on the other hand, must be made shorter as the element spacing becomes greater than one tenth wavelength. Conversely, for spacings less than 1/10-wavelength, the director becomes longer than the driven element.

Now, the above requirements are for maximum gain but, in practice, they are not generally followed. The reason for this is that gain, front-to-back and bandwidth cannot all be optimum with one set of conditions — and since a certain amount of each of these attributes is

desired, the design must be a compromise. So generally, the dimensions are juggled to give what you want most. For example, if you want reasonably good front-to-back and bandwidth, you must sacrifice some gain.

So, you can begin to get a feel for the nearly limitless number of possible combinations. In fact, the best way of exploring all the possiblities would be, first, to design a representative physical model with great care. Then, accompany the design with a computer model which can rapidly scan all the design combinations, coming back to the physical model occasionally to "spot check" the design and keep the computer "honest," which is by way of explaining why ordinary folks like ourselves start with an "empirically-derived" antenna which common sense, hopefully, tells us should work, followed by "cut-and-try" until it does work.

For another look at variables, consider the input impedance for a two-element Yagi, and here is yet another of the compromises involved:

Bear in mind that a low value of radiation resistance (say, 10 ohms) would result in lower efficiency, because of the fixed ohmic losses, which are a constant and would thus be a higher percentage of the total power fed to the antenna. Of course, ohmic losses should be minimized, using large conductors, low-resistance mechanical connections, etc., but it is always better to strive for a higher value of radiation resistance, at least 50 ohms, which would be more efficient and match the coaxial feedline as well.

Another important factor is mutual impedance. The presence of each element influences the actual tuning of the other element.

For example, with the parasitic element tuned for maximum gain, the reactance coupled into the driven element makes it look more inductive when the parasitic element is tuned as a reflector, meaning that the driven element has to be shortened. Conversely, the driven element has to be slightly longer when using the parasitic element as a director. This applies when using spacings from one-tenth to one-quarter wavelength, but not necessarily to other spacings.

And let's look at front-to-back: Tuning for maximum forward gain does not, as I have said, give the best signal-strength reduction from the rear. It is necessary to sacrifice some gain to get the highest front-to-back ratio. This is accomplished by adjusting the tuning (or length) of the parasitic element. The reflector would have to be lengthened a little more for spacings up to a quarter-wavelength, and the director would have to be shortened (with spacings of one-tenth wavelength or more). Tuning for maximum front-to-back is quite a bit more critical than tuning for maximum gain but, if done very carefully, good front-to-back can be achieved with very little sacrifice of gain. Since "you can't work 'em if you can't hear 'em," front-to-back is of more practical importance than gain. Gain for a two-element Yagi with the director tuned for maximum gain, for example, is only 5.5 dBd. With proper tuning, though, front-to-back can be 17 dB, with a gain.of 4.5 dBd or only 1 dB less than maximum.

As far as the directional pattern of the two-element Yagi is concerned, the strength of the front and back lobes will vary, of course, but experiments have shown that the width of the main beam does not vary significantly with the various tunings I have mentioned.

Now one more thing, bandwidth: We must consider, first of all, what kind of bandwidth we mean. Is it the bandwidth over which we want a certain minimum front-to-back? Is it the bandwidth over which we want an acceptable SWR? Or is it a bandwidth over which we want a certain minimum gain? Here again, more variables, more compromise, but generally, we evaluate bandwidth in terms of SWR, since this affects power lost in the transmission line and the match of the line to the transmitter, which in turn affects the amount of power the transmitter will dump into the antenna system. This kind of bandwidth is controlled in large part by the Q of the antenna. Closely spaced parasitic arrays are high-Q arrays and SWR bandwidth will be narrow. The spacings I have mentioned are good compromises and will give usable proportions of front-to-back and bandwidth.

As you can see, the interplay of these and other variables can go on and on. Compromise is the key word. You must decide what you want the most of and be prepared to sacrifice something else to net it. Just imagine, after looking at a simple two-element Yagi, what is involved in a multielement beam.

Here are some references:

All ARRL Antenna Books
Brown, "Directional Antennas," I.R.E. Proceedings, January, 1937
Kraus, "Directional Antennas With Closely Spaced Elements," *QST*, January, 1938
Laport, "Radio Antenna Engineering," McGraw-Hill
Terman, "Radio Engineering," McGraw-Hill
Uda and Mushiake, "Yagi-Uda Antenna," Sasaiki Publishing, Sendai, Japan

THE TWO-ELEMENT QUAD

If two elements are adequate for your requirements (the two-element quad compares favorably with the three-element Yagi), the "boomless" configuration offers several advantages:

1. It is lighter, stronger and will resist the onslaught of ice and wind more effectively than will the boom-type quad.

2. When used as a tribander (for 20, 15 and 10 Meters), the angles of the support arms are such that they allow all three pairs of loops to be spaced the same, expressed as a fraction of a wavelength on that band. Typically, this spacing is 1/8-wavelength for optimum results.

3. When the three pairs of loops are all similarly spaced in this optimum fashion, it is much easier to feed all three driven elements with a common feedline.

4. This compact design allows the antenna to be turned in a 10-foot radius.

To picture this boomless quad, imagine a very small cork ball, 1/2 inch in diameter. Now, take eight toothpicks and stick them into the cork ball so that they fan out into two pyramids, with their apexes butting into each other and their bases as far as possible from each other. Next, imagine six square loops of wire around various points on these toothpicks. First the two largest loops will be around the tips of the toothpicks, and will be the farthest apart — these are the 20 meter loops. Next, place another pair of loops at, say, 1/4 of the way from the two 20-meter loops to the center (the cork ball). These will be the 15-meter loops. Finally, put another pair of loops 1/4 of the distance from the center toward each of the outer 20-meter loops. Let me emphasize that actual spacings are a little different, and that these spacings were simplified to make it easier for you to form a mental picture of the boomless quad. We'll see later how the actual spacings are determined.

Now, let's see what a real live antenna looks like: First, it is built on a so-called "spider" instead of our cork ball. One very popular commercially-available version is the "Gem Quad," using a spider consisting of eight short pieces of aluminum tubing welded together on a mast mount. Those eight toothpicks we used are replaced by eight fiberglass arms. Each of these arms is made of three fiberglass rods bound together as a triangular-cross-section beam, a few inches across at the spider and tapering down until all three rods meet at the outer end to form a virtual point. The lengths of the arms and the angles at which they fan out are the factors which make it possible for all the wire loops to be the right lengths, with the correct spacings between each pair. This involves some compound calculations, and I would think that the ultimate dimensions were derived "empirically," that is, a scale model, followed by a full-size model, with lots of "cut and try" engineering. This procedure would, of course lend itself to "home-brewing" one of these little gems. However, you would be well-advised to check the cost of materials these days, especially the cost of fiberglass components. You may discover that it costs only a little more to buy one that is readymade.

Let's continue with the Gem Quad as a convenient example and look, first, at its physical size. The 20-meter driven element consists of just under 70 feet of wire, which makes a square just under 18 feet on a side. The 20-meter reflector element is just a little longer, of course, about 72 feet, making that element about 18 feet on a side.

Now for the spacing between the loops: Optimum spacing for these compact arrays will be on the order of 1/8-wavelength. To find this spacing in feet:

1. Since radio waves travel approximately 300,000,000 meters per second, we find the wavelength at a given frequency by dividing the frequency, in Hertz, into the speed in meters. However, we can cancel out all those zeros in both speed and frequency, ending up with 300 divided by the frequency in megaHertz, so we take the center-of-the-band frequency of 14.175 MHz and divide it into 300, coming up with a wavelength of 21.6 Meters. Then, we convert meters to feet when we multiply by 3.281, getting about 69.44 feet for a wavelength at 14.175 MHz. Next, since we are interested in 1/8-wavelength, we divide by 8, getting about 8.7 feet for our spacing between the loops. Actually anywhere in the 8.5- to 9-foot ballpark will be OK.

2. Following the same procedure, we will

find that the 15-meter loop is around 48 feet in circumference, making a square approximately 12 feet on a side, with about 6-foot spacing between the loops.

3. Similarly, the 10-meter loop is around 35 feet in total length, just under 9 feet on a side, and spaced slightly under 4.5 feet.

Now for the tuning: First, as I have implied, the common way is to parallel the three driven elements and feed them with a common coax. With this setup, the impedance matching is accomplished in several possible ways:

1. Stub tuning at the feedpoint.

2. The ring transformer, commercially available.

3. A quarter-wave coax matching section.

I mention these in passing, but will concentrate on a better way of doing it:

1. As described on the previous page, calculate the length of wire needed for the 20-meter driven element: 69.44 feet, and make it a couple feet longer, for easy handling and adjusting. Also use the same procedure to calculate the 15- and 10-meter driven elements (add a foot or so to each).

2. Next, calculate the reflectors, exactly as the driven elements, except add 3.5% to the length.

3. THIS IS VERY IMPORTANT: Keep an engineering notebook on what you are doing. Enter in this book (1) the calculated length of the wires and (2) the actual length, including the "safety factor" you have added.

4. String all six wires on the frame, using the spacing indicated on the previous page. Connect the ends of the driven elements temporarily to center-feed insulators, such as the HYE-QUE or the HY-GAIN antenna feedpoint connectors. Both have receptacles for the PL-259 coax connector ... or, you can use a 1:1 balun. The Bencher air-core balun is recommended for this. In any case, this feedpoint is in the center of the bottom of the square loop.

5. Temporarily mount the quad on a pole which will put the bottom of the 20-meter element eight feet above the ground. Use a stepladder to adjust the elements. A portable transceiver and an SWR meter complete the equipment requirements.

6. Now for the feedline requirements: First, prepare a quarter-wavelength coaxial matching section for each of the respective driven elements. One quarter-wavelength of 72-ohm line will effectively transform the 100 ohms (approximately) at the antenna feedpoint to about 50 ohms. For this, you can use either RG59 or RG11, depending on how much power you run. Place a PL259 at each end of these "transformers." Insert one end of each transformer in one of the center-feed insulators, or baluns, as the case may be. The correct lengths of these transformers are:

For the 20-meter loop: 11 ft., 7 in.*
For the 15-meter loop: 7 ft., 8 in.*
For the 10-meter loop: 5 ft., 8 in.*
*(Adjusted to the velocity factor of the coax.)

The other ends of these 1/4-wave transformers are terminated as follows:

a. If a remote coax switch is used (on the tower), the other ends of the three 1/4-wave transformers are inserted in appropriate SO-239 receptacles in the switchbox.

b. If three separate feedlines are run all the way into the shack, the other ends of the three 1/4-wave transformers are connected to the three 50-ohm coaxes with "double-female" PL238 straight adapters.

7. Now comes a point of decision: You can use a remotely-controlled coax switch on the tower and a single coax from there to the transmitter or you can use three coax lines all the way to the transmitter and switch them in the shack. Basically, this decision is one of economics. If it is only 60 feet from antenna to rig, about 50 dollars will buy three RG213 feedlines, and a good three-way manual switch on the desk will coast less than 20 dollars. If, on the other hand, this antenna is 150 feet away and you're running a rockcrusher, a single run of RG213 and a remote switch will cost you about 200 dollars. Even here, you could run three lines and a manual switch for not a whole lot more. Personally, when there is a three-inch ice coating on the tower, at 10 below zero, I like to service the switch in the shack! This method also gives you some added flexibility in leaving you with two good antennas in case something happens to one of them, but a disabled remote switch could put you out of business with all three antennas.

8. Now connect the portable transceiver, SWR meter and a convenient length of 50-ohm coax to the 72-ohm coax matching section (the other end of which is connected to the antenna). Use a PL258, double-female adapter and mate the PL259 on the 72-ohm section to the PL259 on the 50-ohm coax.

9. Use very low power and be careful not to QRM others. Tune across the 20-meter band, looking for the lowest SWR. If this frequency is

below 14.175, shorten the loop a bit and try again. If it is above 14.175, lengthen the loop. Do not cut off the excess wire yet; just temporarily wind it back on itself. When you're sure, trim off the excess wire.

10. Now, measure the wire you have trimmed off. This is where your notebook becomes important: Just subtract the length you have cut off from the total that you started with, and you now know the real length of the driven element.

11. Then, for the reflector length, simply add 3.5% to the finally determined length of the driven element. Since your notebook tells you the total length of reflector wire you started with, you can easily figure how much to cut off in order to end up with the correct length.

12. Repeat the above steps for the 15-, and then the 10-meter pairs of loops.

13. Connect your permanent coax (coaxes) and switch, and raise the quad to its permanent position. It's ready to go.

Keep all your notes. They'll be useful later in many ways. Don't rely on your memory.

This independent feed method is much better than the parallel type. Efficiency, gain and front-to-back are all better. Don't be hasty to judge the front-to-back. Operate for some period of time and you will get a good "feel" for that. Sometimes, a quad may seem to have very little front-to-back, but this is due to a special set of skip conditions, so don't worry about it.

I never use stub tuning if I can help it, because such a device consumes a little power. In the case of the quad, if the loop is the correct length, no stub is needed. I just use stainless steel hose clamps to support the loop's wire guides, thereby allowing me to slide the loop guides to a position (after the length of the loop is determined) which gives the loop the proper shape. This results in a loop that is both more efficient and better looking.

THE 160 METER STORY

THE 160 METER BAND, PART I

Most ham rigs currently available today include the 160-meter band, but many have not used that part of the radio simply because antenna requirements are (or appear to be) too formidable. I hope to tell you, in this chapter, how to decide if you like this band and, in the next chapter, how to go on to bigger and better things if the 160-meter bug does bite you.

First, let's take a look at this band:

Each HF amateur band has a personality of its own, distinctly different from the others. When I think of the 80-meter phone band, for example, I think of older hams, meeting regularly in rather exclusive groups. The 80-meter CW band never seems to be particularly busy and there is a lot of room down there.

The 40-meter phone band is more democratic and strangers are welcomed by most groups, as they strive to maintain a clear channel between the foreign broadcast heterodynes. The old pros inhabit the CW band below 7100 kHz and the Novices are very busy from 7100 to 7150 kHz.

A switch to 20 Meters and the first quick impression is big power and big antennas. Sometimes I am tempted to say, "turn up your speech processor, I can still understand you!" Conversation on this band often consists of trading reports on the most recent exotic DX contacts.

On 15, 1 think of phone patches, missionaries and DX nets and, on CW, a favorite hangout for the Novices.

On 10, of course, they're trading 10-10 numbers, working AM or FM on the upper part, and cross-band to 2 Meters for Oscar.

160 also has some distinctive features of its own. It is known as "the pot-belly stove band" because, in most areas, summer static makes the band difficult to use, so it is a lot more fun on cold winter nights. Also, the lower winter sun is responsible for less "D Layer" absorption, making signals stronger and more enjoyable as we warm ourselves around the pot-belly stove. Other characteristics of the 160-meter band have been changing, though, and we have to break them down into three categories:

1. The way it was.
2. The way it is.
3. The way it will be.

First, since World War II, the operating areas in this 1.8 to 2 MHz band have been severely restricted by Loran navigation stations occupying frequencies ranging approximately from 1850 to 1950 kHz. As a result the hams took what was left and managed to get the most possible out of it by adhering to a self-imposed "gentlemen's agreement." Under this agreement, 1800 to 1810 was alloted to CW, 1810 to 1825 went to sideband and 1825 to 1830 was a "DX window" for DX listening only (and working that DX cross-frequency). Sideband continued from 1830 to wherever the Loran could be heard, which was around 1850.

The AM stations worked up above the Loran, from about 1950 to 2000 kHz. Thus, the band became known as "the gentlemen's band" ... wouldn't such sensible behavior be wonderful on some of the other bands?

Another feature of "the band that was" restricted power to very low levels, sometimes as low as 50 watts at night, in order not to interfere with Loran.

Now, let's see what the 160-meter band looks like today: On June 10, 1981, the Commission gave the amateurs a 160-meter band to call their own. The U.S. Loran stations had been phased out and, finally, with continued urging from the ARRL, the Commission removed the power restrictions from that part of the band covering 1800 to 1900 kHz. This meant that hams anywhere in the U.S. could use the same level of power used on any other band, day or night. There were certain remaining power restrictions, however, from 1900 to 2000 kHZ. Some Canadian Loran remained at 1950 kHz so, the closer you were to Canada, the tighter the restrictions were. Then, on March 27, 1984, the remaining Canadian LORAN having been closed down, the band was opened to full power, day and night, across the entire 1800 to 2000 kHz band.

Incidentally, a unique feature of this band is that no specific "slots" have ever been actually assigned for the various modes. Add to this a large number of new hams who never heard of the "gentlemen's agreement" and you may very well (these days) hear CW, sideband or AM anywhere up and down the band. We are going to have to experience a "shakedown" period as a whole new cast of characters become accustomed to new operating conditions.

And, last, what is the band going to be like in the future? For one thing, I see a daily influx of hams who have never been on 160 before, and this during the summer, when activity is normally at a low level, so things should get quite busy as winter comes on. The ARRL is trying to anticipate and prepare for the increase in population and make it easier for them all to live together in harmony. Accordingly, they have come up with a suggested band plan — a successor, if you will, to the old gentlemen's agreement. This is needed, because the population will be too large and so many will be so new to the situation that going back to the good old days of the voluntary gentlemen's agreement will just never happen. *QST*, August, 1981 has the ARRL band plan, plus much more, including footnotes on other sources.

Another problem we may have to face in the future is the possibility that we could lose half of the band to the commercial broadcasters. If this should happen, they would shuffle some radio-location services to make room for added broadcast frequencies and in the shuffle, we could lose part of the 160-meter band again. However, for the immediate future at least, nothing will probably happen, and with a little luck, maybe it will never happen.

Now, if we have a new rig with 160-meter capability, how do we go about getting on this band? First, try to forget what you know about propagation on the other bands. It's better to start from ground zero, with no pre-conceived ideas. This is a night-owl band, effective from sundown to sun-up, basically.

During daylight hours, "D Layer" absorption limits the signal path to ground-wave distances. This means that a 100-watt rig cannot normally expect to communicate beyond 100 miles during daylight hours. Of course there are exceptions, depending on time of day, time of year and where we are in the sunspot cycle, when 1,000 miles may be possible, but it is not anything to count on.

However, as darkness comes on and the path lengthens, signals start coming in from greater distances. Quite often this will be accompanied by a marked increase in atmospheric noise. This is because a storm front which is in the path can be picked up also. This means that, even if the skies are clear locally, QRN can be S9 or above. Generally speaking, 160 is as much noisier than 80 as 80 is noisier than 40. There are many other fine points concerning utilization of this band which will help to make your operation more effective and enjoyable. In the next chapter, in addition to special antenna considerations, we'll cover some of these procedures in more detail.

At this time, however, I want to finish the session by getting into just the basics regarding 160-meter antennas — enough to get your feet wet and give you a taste of this unique band.

Unlike most of the other bands, just any old piece of wire which will load up won't get the job done here ... but there are some fairly easy ways to get going. For example, if you have a dipole up 40 feet or more, and the feedline is mostly vertical, you have a start. Just pull the PL259 coax connector out of th rig and short the inner pin to the outer shell. You now have a top-loaded vertical. If you connect this to the "single-wire" terminal of a transmatch, you can connect the other end of the transmatch to your rig and tune for 1:1 SWR on the desired frequency. Quite often, it is even easier: An air-variable capacitor between the antenna feedline and the rig will tune out the inductive reactance and get you down to 1:1.

Remember, this is basically a vertical antenna and it wants as much ground system as you can provide. Using your ingenuity, you can employ chain-link fences, tin roofs, copper waterpipe systems in the ground, or any combination of these things which you can tie together, to serve as a reasonably effective ground system.

Ground radials per se can be laid unobtrusively in the grass, pinned down at several foot intervals with stiff wire hairpins. You don't have to do any digging or defacing your lawn. If you do this in fall or winter, they will all blend into the ground and, by spring, you won't even know they are there. Yet, if you wish to take

them up, it is a simple task.

I started with an inverted V 40 feet up (using the feedline as a vertical antenna and the horizontal part as top-loading), and had a lot of fun with it before I got further along. Remember one basic axiom at this point: 160 Meters is a vertically-oriented band. Remember that a horizontal antenna does its best at 1/2-wavelength or more above ground. On 160 Meters, 1/2-wavelength is more than 250 feet! Oh, a horizontal will work pretty well for DX at 80 or 100 feet, but that's still beyond most of us.

On the other hand, all kinds of verticals will work well if they are properly matched and have some kind of ground system. If you have a tower, anything from 40 feet up, with beams et cetera on top, you're in business. You can make a folded unipole, as I have, or you can shunt feed the tower. If it is a non-guyed, self-supporting tower, your job is easy. If it is a guyed tower, there's a little more involved, but not much. In this case, you may be able to use some part of the guys as part of the antenna.

You can also use your tower to support either an inverted "L" or a "Folded Marconi," both of which are simple and easy to erect. Be sure, though, if you use the tower as an antenna, to break up the unused guy wires with insulators ... into short enough pieces (compared to a wavelength) not to resonate and work in conflict with the antenna's normal radiation.

There are so many antenna possibilities among you that it is not within the scope of this discussion to cover them all, but let me know about your setup and I will happy to offer more specific suggestions. Just send an SASE. Meanwhile, tie the inner and outer conductors of that coax together and use a transmatch or variable capacitor to match it. It might bite you!

THE 160-METER BAND, PART II

This time we'll round out the 160-meter category with a discussion of the ins and outs involved in operating on this band, plus tips on improving your received signal.

In the last chapter, I described the band (1) as it was in the past, (2) as it is today and (3) as it may be in the future. I also described some basic antennas for 160 Meters. First, though, let me review the proposed ARRL band plan for 160:

1. 1800 to 1825 kHz exclusively CW, as on the other bands.

2. The "DX Window" from 1825 to 1830 remains. Remember, listen only in this window. If you hear nothing, it doesn't mean that DX is not being heard and worked by somebody out of your range.

3. There will be another DX window (again, for listening only) from 1850 to 1855 kHz.

4. For the present, the frequencies between the two DX windows (1830 to 1850) are now used for both CW and phone, but will probably become DX phone only in the future.

5. All above 1855 is to be for phone.

6. The Japanese can transmit only from 1907.5 to 1912.5 kHz. You listen there and either they will tell you where to transmit, or you can transmit on some other frequency and tell them where to listen. You will always transmit to the JAs somewhere around 1800 to 1810 kHz.

NOTE: The ARRL Band Plan was written before the restrictions were lifted from 1900 to 2000 kHz ... so it could be changed again in the future.

As I mentioned last time, propagation conditions are different from those encountered on other bands. The band begins to pick up at or near sunset and, generally speaking, gets stronger as darkness sets in. This, of course, is similar to the situation on 80 Meters, but it differs otherwise.

There is a phenomenon known to 160-meter DXers as "sunset skip," or "sunrise skip." DX signals often peak just as you see the sun either appear or disappear over the horizon. The DX will be heard from the west at sunrise and from the east at sunset or, in some cases, anywhere along a north/south border between light and darkness. DX contacts are often made when the band sounds punk otherwise. Hawaii is most often worked when you can just see the rising sun peek over the horizon, or slightly before. South Americans and Europeans come up from full darkness until sunrise. I must emphasize, however, that 160-meter propagation is unpredictable, one of the things that makes it fascinating ... And the receiving challenge:

One of the most common amateur truisms is, "If you can't hear 'em, you can't work 'em" ... and this goes double on 160, with its formidable atmospheric and man-made noise levels ... not always, but frequently.

Now, I've been saying that a vertical antenna is best for this band, so I must take time to qualify that statement, emphasizing that it is great for transmitting ... but, as yo know, the vertical does love noise, most of which is more vertically than horizontally polarized. So, most successful DX operators us a separate antenna (or several different types of antennas) for receiving. One excellent receiving antenna for 160 Meters is the Beverage, developed way back in the early 20s, but it does require lots of real estate. It is, in its simplest form, just a straight horizontal wire, close to the ground and on the order of 1,000 feet long. If it is not terminated, it will be bidirectional, with the greatest signal strength coming from each end. If the far end of the wire is terminated, it will be unidirectional, with an even stronger signal coming from that direction. The terminating resistance is equal in value to the receiver input impedance. The signal received by this antenna is remarkably low in noise content, but you don't get something for nothing. It is a terribly inefficient antenna. If you tried to use it for transmitting, most of the power would be consumed in the ground, which means that you need a very good receiver and, in most cases, a low-noise preamp with 25 or 30 dB gain. You can use someting like the Ameco preamp, or it is fairly easy to put together a two- or three-stage untuned transistor-type preamp.

Of course, for most of us who don't have room for a Beverage, a good compromise is a small loop antenna. It can be four or five feet in diameter, or even smaller, so that you can have it in the shack and rotate it by hand, to null out unwanted QRN and QRM. This kind of loop can be homebrewed quite easily. It should be a shielded loop, involving several turns of wire inside a loop of aluminum or copper tubing or conduit. For convenient construction, you can make it a square loop and put it together with standard 90-degree elbows at the four corners. This makes it easy to thread the insulated wire inside the shield. It is important that the outside shield be broken, usually at the top, and joined with something like PVC tubing. Otherwise, the shield loop would form a shorted turn, and the relatively heavy current flowing in it would nullify the effectiveness of the antenna. Loops and preamps will be covered more completely in the following chapter.

And here are a few more thoughts on 160-meter operating techniques:

First, DX on 160 is not easy, especially until you get used to the locations, frequency-wise, and the split-frequency combinations. You will hear most of your DX in the 1825 to 1830 window, and never, never transmit there. If you answer them on 1800 to 1810, they will be fanning the dial in this area and will find you. In this case I am talking about CW. For phone DX, you will generally be able to work them not too far above or below the window.

Don't forget that, on phone, you will be on lower sideband. This means that, if you are using much power, you will be heard two or three kHz below your indicated operating frequency ... so don't operate merely one or two kHz above 1830, or the fallout from your signal will be QRMing the upper part of the window. This makes avid DXers very unhappy, and you will probably be advised that you are in the window, even if your dial says otherwise.

The Hawaiian stations have usually worked cross-frequency to the states from up near 2000 kHz ... and they listen down near 1800 ... but I have also been working them down in 1800/1900 area.

For cross-frequency DX operation, you will need a separate receiver or a remote VFO. Actually the separate receiver is more useful because you can listen to both frequencies simultaneously. Ten Tec has, I think, the only remote VFO that can do this. The ability to hear both sides prepares you to break quickly after the previous QSO terminates. This split-second timing often snares a contact you might otherwise miss.

A word about calling CQ on CW: The 160-meter band just doesn't have the room to accomodate the fellow who calls endlessly, waits only 5 seconds for a response and then calls endlessly. Short calls plus an adequate period of listening for answers, will help the other fellow and it will help you, too. However, if you have followed this procedure several times, and you just don't hear anything or anybody, you are then justified in calling for a longer period ... but listen for a reasonable length of time after calling, instead of jumping back in before that weak signal gets a chance.

And finally, if it seems that I've spent an inordinate amount of time on DX, and don't let me mislead you ... this band is, for most of us, 95% friendly rag-chewing and 5% DX. Many winter nights, a casual conversation between two fellows will end up in a round table that goes on for hours and, unlike some of the other bands, there are no strangers. No band features such a wide variety of unorthodox antennas and you will hear much trading of antenna ideas, plus a higher percentage of amateurs who are knowledgeable on the subject. Give it a try. It won't cost much to get your feet wet.

RECEIVING LOOPS AND PREAMPS

Whether or not you need a receiving loop, the subject is an interesting one, since the basic considerations involved serve to illustrate several fundamentals of antenna and propagation theory. The loops I will cover here are physically compact and especially useful on 160 and 80 Meters, and for shortwave DX listening. These loops are actually derived from those used as direction finders, so I will start with some direction finding principles and relate that to the use of similar loops for receiving.

Since an RF radiation field contains a magnetic component, it follows that a coil of wire placed in proper physical relationship to that magnetic component will absorb energy from the field, thus serving as an antenna. Physically, this loop may take the form of a single turn, several turns or even a helix. It can be a triangle, a circle or a square. For true loop operation, the circumference should be less than 0.08 wavelength, at the frequency of operation. By "circumference," I mean the total length of the wire in the loop. For example, one loop that I use is approximately 3 feet in diameter. It has 4 turns ... one turn is 3.14 times the diameter, or 9.42 feet ... 4 times 9.42 is 37.68 feet, which is about 0.07 wavelength on 160 Meters.

This loop can be either resonant or non-resonant, although signal pickup will be appreciably better when the loop is resonant on the desired frequency. The pickup pattern will be the same for both types if there is no stray pickup and the loop is perfectly balanced to ground. Unbalance of a resonant loop will have the effect of making otherwise very sharp nulls less distinct.

If the loop is unbalanced, the whole loop will work against ground. This is known as "Marconi effect" or "antenna effect." In such case, resulting added current induced will combine with the true loop current, giving something other than the desired pattern ... but if the loop is resonant, the phasing of the loop currents will continue to maintain a symmetrical pattern with nulls no longer so sharp. Incidentally, the ideal pattern of this loop (resonant and balanced) is a perfect figure eight. Looking down on the loop from above, the ideal pattern appears as two perfect circles, just barely touching. As you can see, the resulting nulls are very sharp. Now, if you draw a line tangent to both circles at their intersection, this line will indicate the direction of minimum signal strength, with the two minima 180 degrees apart. Then, if you draw a line across the intersection of the circles, at right angles to the null line, this line will coincide with the plane of the loop. You can see, therefore, that the complete nulls are, ideally, broadside to the loop.

Again, as long as the loop is resonant, the pattern will remain symmetrcal, with the nulls being softened if there is unbalance. However, if the loop is non-resonant, the combining of "Marconi effect" currents with true loop currents will cause them to add in some directions and cancel in others. This results either in nulls that are no longer 180 degrees apart or, in some cases, only one null. Obviously, this would not be desirable for accurate direction finding, and its effectiveness as a noise-cancelling loop would also be compromised.

So far, I have not yet mentioned shielding of the loop, but shielding is highly desirable. For instance, rain static is an electrostatic type of discharge; therefore, if we enclose the loop in, say, copper or aluminum tubing, or in electrical metal conduit, we keep out the rain static, while letting in the desired electromagnetic signal component. The shield also virtually eliminates the "Marconi effect" which would otherwise result from unbalance to ground. Of course, it is very important to put an insulated gap somewhere in the loop shield since, if it were allowed to function as one big shorted turn itself, the resulting high circulating current would nullify normal operation of the loop.

I want to emphasize, at this point, that everything stated thus far is predicated on conditions when the ground wave strongly predominates, as on 160 in the daytime ... but when there is appreciable skywave propagation (after dark), the loop, used as a direction finder, will give inaccurate bearings because downcoming sky waves, horizontally-polarized,

will excite the horizontal portion of the loop and confuse the normal nulls. For obvious reasons, this is called "night effect" ... and since most 160- and 80-meter activity is after dark, this is one reason we should not expect the loop to be a complete panacea.

Next, since this very inefficient antenna will be down, say, 25 dB below your regular antenna, you will nearly always need some low-noise preamplification to bring the signal back up to a usable level. There are many kinds of preamps being used by the 160-meter buffs; the Ameco is a good one. Of course, many hams will prefer to build their own, which is a good idea because, first, it is often desirable to put it in a minibox and mount it right on the loop. Second, impedance matching, especially between the loop and the preamp input, is important. For example, if you have a high-impedance resonant loop and you want to couple it directly into the preamp, the preamp must have a high-impedance input, but most bipolar transistors, operated normally, have low-impedance inputs (this applies to Ameco). To overcome this obstacle, you can use a small ferrite ring (from Radio Shack) and wind a toroid transformer which will step this impedance down from high to low ... or you can use a bipolar or FET transistor as an emitter-follower, providing high impedance to the tuned loop. However, many seem to prefer a pickup loop of about two turns, right in the same shield with a four-turn resonant loop. The resonant loop is allowed to float, and the pickup loop, which is low-impedance, can work right into a conventional bipolar transistor. However, there is another desirable refinement: as I mentioned before, the sharpest null needs a balanced condition. It is more desirable, therefore, to center-tap the low-impedance pickup loop and ground at that point, feeding both ends of the pickup loop to a balanced preamp input. This balanced preamp input can be provided by using the above-mentioned toroid transformer. The center tap in the primary of this transformer will also be grounded.

Another popular preamp (home-brew) uses a Motorola chip, the MC 1350, an 8 DIP op amp featuring a complete IF amplifier, with 60 dB gain, AGC, remote level control, etc. It has a balanced, low-impedance input, which is just what you need to match the balanced pickup loop, eliminating the need for the toroid transformer. This chip is also available from Radio Shack as their #276-1758, for just over $2.00.

Here's what some of my 160-meter friends are doing with loops: Ed, K9LUQ, Antioch, Illinois, is using the loop I have described, plus the Motorola 1350 preamp. He discovered, the hard way, something that could benefit the rest of us: His loop picked up his radiated signal so well that the RF blew the 1350 op amp. He then discovered that a pair of small 916 diodes could be cross-connected, right across the balanced input of the chip. This doesn't inhibit the desired signal at all, but before the signal gets strong enough to hurt the chip, the diodes will conduct and short the RF.

Bob, KM9C, Sycamore, Illinois, used some 7/8" copper tubing for the loop shield, making it 2.5 feet in diameter. For the loop inside, he used two lengths of the kind of stiff twin-conductor wire the phone company uses for burying purposes. Then he was able to simply push this stuff through the pipe, after which he properly cross-connected the wires to make it a four-turn loop. This allows all four turns inside the loop to be parallel, instead of being twisted, assuring better performance. He uses just one more turn for the pickup loop and his home-brew preamp uses plain bipolar transistors, with the first stage being an emitter-follower for the high-impedance input needed ... and I can tell you that Bob seems to copy everybody, no matter how noisy it gets. These loops are intended to be used right in the shack, rotating them to null out the unwanted QRN/QRM. Bob has his suspended from the ceiling and he can reach up to turn it.

Jim, W5LDU, Belton, Texas, had four turns in a shield, plus a pickup loop of two turns, with a grounded center tap. His latest loop, though, is two feet in diameter and has seven turns. This still keeps the total length under 0.08 wavelength, and his pickup loop is still two turns, with the center tap grounded. Jim uses his loop a great deal, and he tells us that, for short range, it is stronger than the big antenna, but that for longer range it is not as effective, and the big antenna will work as, well or better, if the desired signal is, say 1,000 miles or more away. Also, Jim is the one who discovered the Motorola 1350 chip for us. Jim is very helpful in advising others on loop construction details, but always winds up by telling them, "don't expect it to work miracles."

Dale, KIØL, Joplin, Missouri, has a loop made of heliax, so it is a single turn, and he cut a piece out of the outer conductor, at the top of

the loop, to break it up. He also uses the 1350 chip. However, he had a problem resulting from the fact that he had to move the loop to an outside location because of undesirable pickup ... until we did a little research and came up with a solution: The problem was simply that the big transmitting antenna was also a very good receiving antenna ... so good, in fact, that it also received a lot of the unwanted stuff ... it received it so well that it was also able to re-radiate some of it. This meant that the loop had the impossible job of nulling it out when it was coming from two directions: (1) the original source and (2) the reradiation from the transmitting antenna. The answer to this is to use a pair of spare contacts on your transmit-receive relay to activate a relay that will disable the transmit antenna when receiving. How you do this depends on the type of transmitting antenna — you may have to ground it, or open it up, or insert a coil to detune it. Then the loop can be used to tune in the wanted signal and null out the unwanted stuff.

CONCLUSION

If you've gotten this far, I hope you have read in sufficient depth to observe that we have never strayed far from the central theme established in Chapter 1, "The Easy Way."

As inspired by Walter Maxwell, we tried in many ways to place the usual superstitions and "old wives' tales" in perspective, hoping to encourage and enlist your belief in something different and better ... yet, it is so difficult to get away from that old feeling that the antenna won't work if it isn't resonant ... and, while trying to think of a way of leaving you with one final strong impression, I remembered a letter I received a short time ago from Bud Brown, WA5RKX, in Lubbock, Texas ... His letter draws a vivid word-picture of what I am trying to get across to you in this book ... so, just read Bud's letter below, I can't think of a better way to ring down the curtain on "The Easy Way" ...

Thank you es 73,

John, WB5IIR

Dear John,

I hope you're satisfied. You have completely ruined Amateur Radio for me. For sixteen years now I've been contentedly hamming away and thoroughly enjoying myself. I could meld into any round-table and hold forth for hours on end about a multitude of topics. I never flinched when told to cut my antenna to an intended operating frequency in order to always have a 1:1 VSWR despite excursions up and down the band. I never questioned the assertion that tuners soak up most of your power and that reflected power came back down the line and zapped your finals. I could go on but you surely get the point by now.

A QSO with you a few months back was followed quickly by the tract "The Easy Way," which prodded me to prove what was said therein. Well after some remedial-type study, I found you were indeed right, and at that moment I ceased thinking of antenna systems in terms of voodoo, witchcraft, and old wives' tales.

Well, surely you can imagine what kinds of trouble that got me into with my old buddies. No more am I on the inside. Now my friends warily circle around any mention of antennas rather than listen to the heretic from Lubbock. In short, I am considered to be "beyond the pale" on any technical topic. See what you went and done!

My only hope now is to work on my old buddies and get the result you got with me. If that doesn't work, I'm finished. Jonathan Swift said, "You can't reason a man out of something he wasn't reasoned into." That worries me. Thanks for nothing, John.

Bud, WA5RKX

INDEX

Anchors 41
Anderson, Walter 11
Antenna Efficiency 19
Antenna System 12,14
Antenna Terminology 18
ARRL Antenna Book 12,24,78
ARRL Handbook 21
Attenuation, line 12,17

Badger, George 25
Balcony Vertical 70
Balun 14,15,17,24
Balun, Choke-type 28
Balun, Coaxial 25
Base, Tower 40
Beads, Ferrite 28
Belrose, J.S. 61,62
Beverage, H.H. 64
Broadband 15
Brooke, E. Y. 52
Brown, Dr. George 30,76
Bug Catcher 73
BX Tower 37
Byrne, John 52

Charge 21,23
Choke Balun 28
Climbing 42
Coax 33
Coaxial Balun 25
Coaxial Dipole 54
Collins 26,50,51
Conjugate Match 14
Crankup Towers 37,38
Current 21

D Layer 87
DDRR Antenna 61
DeMaw, Doug 58,59,64,65
Dipole 44
Director 79,80
Dome, Robert 62
Double Bazooka 54
Ladderline 33,54

Easy Way 10
Efficiency 19,20,72,74
EIA 39,42
Energy 21,22
End-fed Zepp 47-49
English, W. E. 62
Extended Double Zepp 49

Feedline Length 27,28,46,68
Feedline Terminology 21
Feedpoint Impedance 18,19,20,44
Ferrite Beads 28
Ferrite Cores 25
Fisk, Jim 10,12
Folded Umbrella 16
Folded Unipole 66
Foldover Towers 37
Free-standing Towers 37,38

G5RV 45,50
Gentlemen's Band 86
Gamma Match 16
Gin Pole 42
Grid-Dip Meter 62
Ground Conductivity 32
Ground Loss 19,20,72,73
Ground Resistance 20,72,73
Ground Rods 31,32
Guyed Towers 36
Guys 40

Ham Radio Magazine 25,68
Hardware,Tower 41
Hawker, Pat, G3VA 53,78
Hot Tamale 69
Hustler Antenna 69,74

Impedance Matching 13,16
Impedance of Space 55
Inverted V 45

J Factor 14

Kellogg, E.W. 64
Kraus, John,W8JK 30,76,78
Safety 39

Leakage Reactance 24
Light Waves 22
Lightning Protection 31
Line Attenuation 12,17
Line Voltage 23
Low Pass Filter 14
Loop Radiation Resistance 18,19,20

Maintenance, Towers 41
Masts 38,67
Maxwell, Walter, W2DU 10,17,
21,23,24,29,30,46,54,55,67
McCoy, Lew 48
M.I.T 54
Mobile Antennas 69,72
Moxon, L. A., G6XN 47,78
Myths 13,14

Nagle, John 53
Non-Resonant Antennas 12,17
Nylon Guys 42,67

One Hundred Sixty Meters 86
Omega Match 59
Orr, Bill 25,47,78

Pi Net 11,13
Phase Relationship 22
Portable Antennas 69,70
Power, RF 21,22,23
Powis, Raymond 62
Preamps 92

Q 72
Quad, Two- Element 82

Radiation Efficiency 18,19,20,72,73
Radiation Resistance 18,19,20,44,61
Radio Handbook 47,48
Receiving Loops 91,92,93
Resistance, AC 19
Rohn 36,37,40,41,67
Roof Mounts 38
Reflector 79,80
Rice, Chester 64

Saxton 33,67
Skin Effect 27,30
Slinky Antenna 70
Slopers 58
Smith, Woodrow 47
Spaulding Tower 37
Standing Wave 22
Stubs 54,55
Suitcase Antenna 70
SWR 10,15,22

Terman 63
Torque 41
Towers 36,39
Transformer, Coaxial 25,26
Transmatch 13,14,16,48,51,67
Tripods 38
Tuned Feeders 46

Umbrella, Folded 16,68
Unipole, Folded 66
Ultimate Transmatch 48
Uda, S. 79

Varney, R.L. 50
Vacation Antennas 69
Vertical Antennas 30

W8JK 60,76
Windload 39,40,41
Wind Zones 39
Windom Antenna 52
Wysall, Charles, W8TV 54

Yagi 79

Zepp Antenna 47
Zipcord Antenna 69

The Easy Way HF
Antenna Systems

ISBN 0-9705206-4-6

WORLDRADIO BOOKS
2120 28th Street
Sacramento, CA 95818
916/457-3655
www.wr6wr.com